OPERATING MANUAL

FOR

"SCHEDULER" MODEL PT

PROTOTYPE

Irrigation Scheduling Device

July 1985

SOHIO AGRICULTURAL TECHNOLOGIES
4440 WARRENSVILLE CENTER ROAD
CLEVELAND, OHIO 44128

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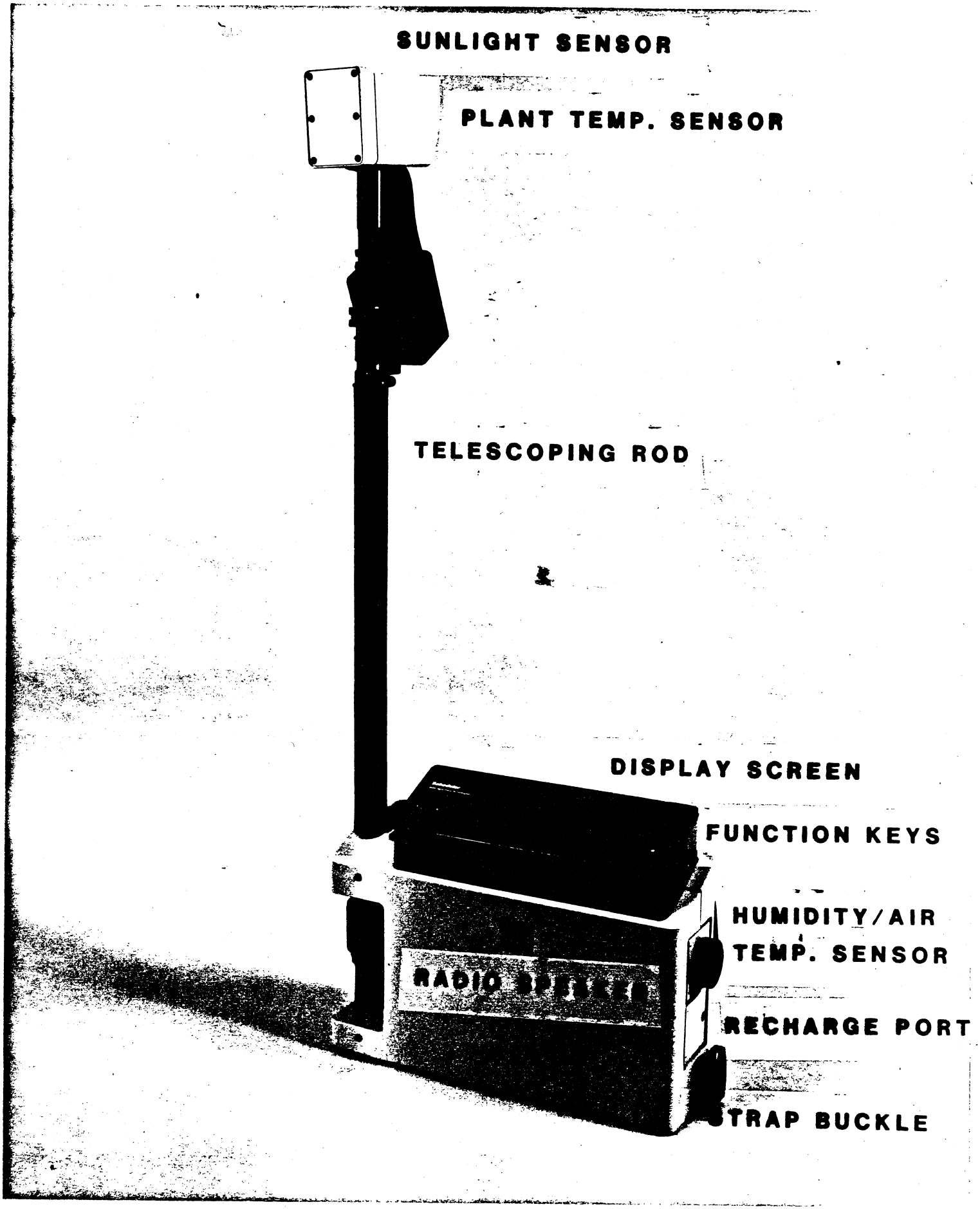
1.1 INSTRUMENT DESCRIPTION



1.2 TECHNICAL DESCRIPTION

The plant temperature sensor is an infrared thermometer which can remotely detect the temperature of an object. The field of view of the instrument has a set focus with an effective range of infinity. Whatever target in the field of view will be seen and the temperature detected. Consequently, care must be taken to aim the instrument at an angle and direction which insures that only plants (no soil, trees, etc.) are viewed.

The air temperature and humidity sensors are located on the inside of the door. It takes 1-2 minutes before the sensors fully equilibrate with the outside air.

2.0 OPERATION

Steps:

1. When removing the instrument from an air-conditioned environment, it should be allowed to stand outside in a shaded area for about one hour so that the sensors can equalize to the ambient conditions.

2. Hold the machine in an upright position at chest height.

3. Slip left arm into harness strap and bring the strap around to the right side across your back.

4. Insert the strapbuckle into the buckle on the right side of the instrument.

5. Adjust the straps for length until the instrument feels comfortable and you can reach the function keys on the display screen easily.

6. Go to a grass area or open area near the field to be measured, and adjust the height of the telescoping head to one (1) to two (2) feet above the plant canopy to be measured.

7. You are now ready to turn the instrument on. Press the on/off function key (upper left-hand corner). The display shall read as follows:

   "Irrigation Scheduling Program, Copyright May 1985, Program Initialized, Press Hum. or Temp."

   You now have the option of measuring air temperature and humidity or measure plant temperatures.

8. To measure humidity and air temperature, open the door on the right side of the instrument. Wait 1-2 minutes for the sensors to equilibrate. Press the "Hum." to record the data.

9. To measure plant temperature, aim the temperature sensor at an angle from which you cannot see any soil or other objects and walk through the field. Press the "Temp." key when a stable reading appears on the screen. For a short crop, such as cotton, it may be possible to view sufficient area from the edges of the field. You must complete steps 7 and 8 within 20 minutes. We recommend a minimum of 30 temperature samples per field.

10. If you are in the field and decide to start over again, press the yellow dot key and the "Reset key" simultaneously. Then turn the instrument off, then on again to restart New Crop Temperature reading. When you complete the plant temperature measurements, you will have to remeasure the air temperature and humidity outside the field.

11. You should "reset" the machine or end the data collection when:

    a. the sunlight begins rapidly changing or changes significantly from its value when the data collection began. We recommend strongly that measurements be made only when the sun is unobstructed by clouds. If necessary, measurements can be made under cloudy conditions if the cloud cover over the sun is relatively constant and the cloud cover is not too thick.

    b. more than 20 minutes have elapsed since the data collection began.

12. To end the data collection, press the yellow dot key and the "Calc" key simultaneously. If you started the data collection with the "Plant Temp." key, the instrument will prompt you to now measure air temperature and humidity.

13. The instrument will display summary data, including the average canopy temperature, relative humidity, air temperature, and the value of SOHIO's stress index and an irrigation recommendation.

14. The optimum time of day for using "Scheduler" is between one and three hours after the sun is "due South." Generally this occurs somewhere around 2:00 - 5:00 p.m. depending on your location. Measurements can be made earlier, but may result in decreased sensitivity of the stress index used by SOHIO.

15. In case the "Temp." key is accidentally pressed or an erroneous reading is made, an observation may be deleted by pressing the yellow key and "Delete" simultaneously.

16. The "Scheduler" records all data measured, including the date and starting and stopping times. If you use the "Scheduler" on more than one field, we suggest you either make notes of which fields you measure on what days, and establish a systematic way of measuring the fields (i.e., always do field #10 before field #6, etc.).

17. SOHIO will be responsible for maintaining the instrument and providing technical assistance.

18. If at any time you feel "Scheduler" is providing erroneous recommendations, feel free to use your best judgment about what to do concerning when you irrigate. From a scientific viewpoint, we are interested in the "failures" as well as the successes. However, we do not expect you to risk damaging your crop. Our purpose with "Scheduler" is to help you. You may cancel your evaluation of "Scheduler" at any time.

19. It is important to take your temperature readings in those areas you are most interested in. For example, if you like to irrigate when a specific area gets dry, then sample primarily in that region. If your field is uniform, then a random sample may be more appropriate. The decision of exactly where to sample will be determined by your knowledge of the field, as well as the type of irrigation system you use.

3.0 PRECAUTIONS

1. Transporting or storing the instrument in air-conditioned locations and then going directly into a hot field may give unreliable data and recommendations. The instrument should be as close to outside air temperature as possible.

2. When transporting the instrument, it should not be exposed to severe mechanical shocks. The unit has been designed to withstand the normal jarring which occurs during transportation.

3. When transporting this instrument, the telescoping tube for the sensor head should be retracted completely.

4. This instrument should not be used in the rain since it is electronic. This could result in permanent damage to the "Scheduler."

5. Do not attempt to obtain humidity or air temperature readings while smoking. Smoke will damage the humidity sensor.

6. Do not attempt to open this unit.

7. Before transporting, cover the plant temperature sensor and the display screen, and close the humidity sensor door.

8. Do not turn the unit off if the program is running. Prior to turning the instrument off, the word "OK" should appear on the screen. An "OK" can be generated at any time by pressing the yellow dot key and the reset key simultaneously.

4.0 EXAMPLES OF DISPLAY SCREEN

1. When first turning the instrument on, it should read:

   "Irrigation Scheduling Program"
   Copyright May 1985

   Function Selection:

   1. Press "HUMID" key to sample humidity.

   2. Press "TEMP" key to sample crop temperature.

2. If you press "HUMID" key, the following will be displayed:

   Relative Humidity = _____ Air Temp = _____
   Make sure Humidity door is open!

   Press "HUMID" to measure air temperature and humidity.

   NOTE: This key must be pressed two times to take adequate readings. If readings are adequate, the following statement will appear: "Close Humidity Door and Press 'TEMP'."

3. When you press "TEMP" key, the following is how the display will look:

   Point sensor at crop, center bubble in level, and then press temperature key.

   When key is pressed again, the following is the display:

   Crop temperature = _____; Radiation = _____; Number of OBS = _____. Press "TEMP" to measure crop temperature.

4. When sufficient crop temperature readings have been taken, you can press the "CALC" key. The following is the display:

   Air Temperature = _____; Crop Temperature = _____;
   Relative Humidity = _____; OBS = _____; Battery Voltage = _____; Average Stress Index = _____.

   And one of the following recommendations will appear:

   IRRIGATION RECOMMENDED — Crop has reached threshold point — See explanation #1.

   IRRIGATION RECOMMENDED — Uncertainty in threshold value — See explanation #2.

IRRIGATION RECOMMENDED — Some hot spots detected — See explanation #3.

IRRIGATION RECOMMENDED — Crop is too warm — See explanation #4.

IRRIGATION RECOMMENDED — Crop temperature is too high — See explanation #5.

IRRIGATION NOT RECOMMENDED — See explanation #6.

NOTE: The instrument is programmed to delete observations which are outside normal operating limits for corn. This type observation will result in an error message appearing on the screen.

ERROR MESSAGE:

"Sunlight is varying too much". With this message you must decide to stop observations or to restart the total procedure again by exiting the program (yellow dot key and reset key) and turning the machine off.

5.0 EXPLANATION OF IRRIGATION RECOMMENDATIONS

There are six explanations relating to the "Scheduler" recommendations.

1. The SOHIO Irrigation Scheduler calculates a primary index exceeding 0.2. This index goes from 0.0 to 1.0. An index of 0.2 or less (including negative numbers) means there is no yield reducing stresses on corn. Indexes above 0.2 indicate yield reducing stresses. It is recommended that you irrigate. The first index is considered the most reliable. However, under certain conditions, other indexes may indicate the need for irrigation. These are described below.

2. Under high humidity conditions, there are increased uncertainties in the primary index. This recommendation will take into account this uncertainty.

3. The field in general does not seem to require irrigation, but a few stressed locations have been detected. You may choose to irrigate the whole field on the basis of these locations or wait a few days more until the field in general requires irrigation.

4. The crop temperature is sufficient that stress is occurring. The evaporative demand on the plant is greater than the roots can supply. This may occur when there is high radiation loads with hot, dry winds. Under these conditions, irrigation may be of no value if soil moisture is not limiting. We do not expect explanation #4 to appear on your screen at all. If it does, it will be a matter of extreme interest to us, and we would appreciate notification.

5. This index indicates that the crop temperature has exceeded our calculated maximum limit. Irrigation is recommended.

6. This means that SOHIO's main index and its four alternate indexes have not detected stress. We conclude no stress is present (i.e., no irrigation is required).

It is important to remember that plant stress may be caused by a number of factors, such as water stress, mineral stress, and plant diseases. If a crop is well-watered, but sick, the "Scheduler" may indicate the need for irrigation. If you are confident that water stress is not a problem, yet "Scheduler" indicates stress, you should consult with a crop specialist to determine the problem.

6.0 WEATHER RADIO

The National Weather Service broadcasts a weather forecast in many regions of the country. If such broadcasts are available, they may be of interest to you in deciding whether or not to irrigate.

7.0 STORAGE

1. The instrument can be stored between 40°F and 100°F.

2. The storage area should be away from all hazardous or corrosive fumes (e.g., acids, bases, insecticides, herbicides, fertilizers, and smoke).

3. Always replace the lens cap on the plant temperature sensor and close the humidity port on the side of the instrument.

4. Close the folding cover over the keyboard to protect the display screen.

5. This is a valuable instrument and should be kept in a secure location.

7.1 BATTERY CHARGING

The unit is capable of operating from 9 to 12 hours on a full charge. It can be recharged in 16 hours using standard 110-120 volt AC 60-cycle electrical outlet source. The batteries in this unit are a sealed lead acid type. The unit can be placed on charge after each use to maintain the battery charge.

7.2 CLEANING

If it becomes necessary to clean the instrument, a damp cloth can be used to wipe all outside surfaces. To clean the lens, a soft cloth or eyeglass paper may be used.

7.3 TROUBLESHOOTING

If the display does not operate, the unit probably needs recharging. If anything else malfunctions, call SOHIO for service. We will either fix the problem or replace the instrument.

For Assistance Call:

Dr. Bronson Gardner	216-581-5996	(Cleveland, Ohio)
Dr. Melvin Keener	216-581-5735	(Cleveland, Ohio)
Dr. Emil E. Pierson	402-466-6897	(Lincoln, Nebraska)

RESEARCH AGREEMENT

THIS AGREEMENT, effective this _____ day of _____, 1986, between The Standard Oil Company, a Corporation of the State of Ohio, referred to hereinafter as "SOHIO", and _____ to be referred to hereinafter as "COOPERATOR". SOHIO and the COOPERATOR will be studying and demonstrating the use of SOHIO's proprietary instrument in determining irrigation requirements for this program. In consideration of the rights and obligations herein set forth below the parties agree as follows:

SOHIO will provide COOPERATOR with the instrument for determining irrigation requirements for a test area. SOHIO will maintain ownership of the instrument and COOPERATOR will return the instrument to SOHIO at the completion of the program or upon receipt of written notice from SOHIO. SOHIO will instruct the COOPERATOR in the intended use of the instrument. The COOPERATOR will use reasonable care in handling and storage of the instrument which shall include adequate security. COOPERATOR will be responsible for using the instrument for collecting data. COOPERATOR will be responsible for maintaining records of irrigation on the test area by location, date and time for purposes of result comparison. COOPERATOR will not tamper with the instrument.

SOHIO will have reasonable access to the instrument during the program for calibration, maintenance, repair, data retrieval and the like during the term of the program. SOHIO will not be liable for damages that may occur to the crops in the test area by following the irrigation recommendations of the instrument.

Information such as designs, data, drawings, know-how, observations, techniques, inventions and the like relating to the program shall be exclusive property of SOHIO and all rights, title and interests shall reside with SOHIO. All information provided by SOHIO pursuant to this Agreement shall be treated as confidential information. The COOPERATOR agrees at all times that the COOPERATOR will make no disclosure of the confidential information to any third party unless expressly authorized in writing by SOHIO to do so.

COOPERATOR agrees that all inventions, improvements and developments in the processes or instruments conceived or developed as a result of COOPERATOR's participation with SOHIO in this program, shall be disclosed to SOHIO but otherwise shall be held confidential as indicated above, and COOPERATOR agrees, at SOHIO's expense, to secure all intellectual property rights therein to SOHIO by signing Patent applications, assignments and any other papers.

It is understood that in rendering COOPERATOR services to SOHIO, COOPERATOR will be acting as an independent contractor and not as SOHIO's agent.

If COOPERATOR agrees to the above terms and conditions, please indicate your acceptance in the space provided below and return one copy of this to SOHIO. This shall then constitute an agreement between us.

THE STANDARD OIL COMPANY	COOPERATOR
BY: _____	BY: _____
DATE: _____	DATE: _____

SCHEDULER™

Plant Stress Monitor

Owner's Manual

Standard Oil Engineered Materials Company

Copyright May 1986

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SCHEDULER™ Plant Stress Monitor Owner's Manual

About this Manual

This manual helps make the setup and day-to-day operation of your Scheduler™ plant stress monitor quick and easy, even if you've never worked with a computer before. The manual takes you step by step through each procedure, with photographs and illustrations to guide you.

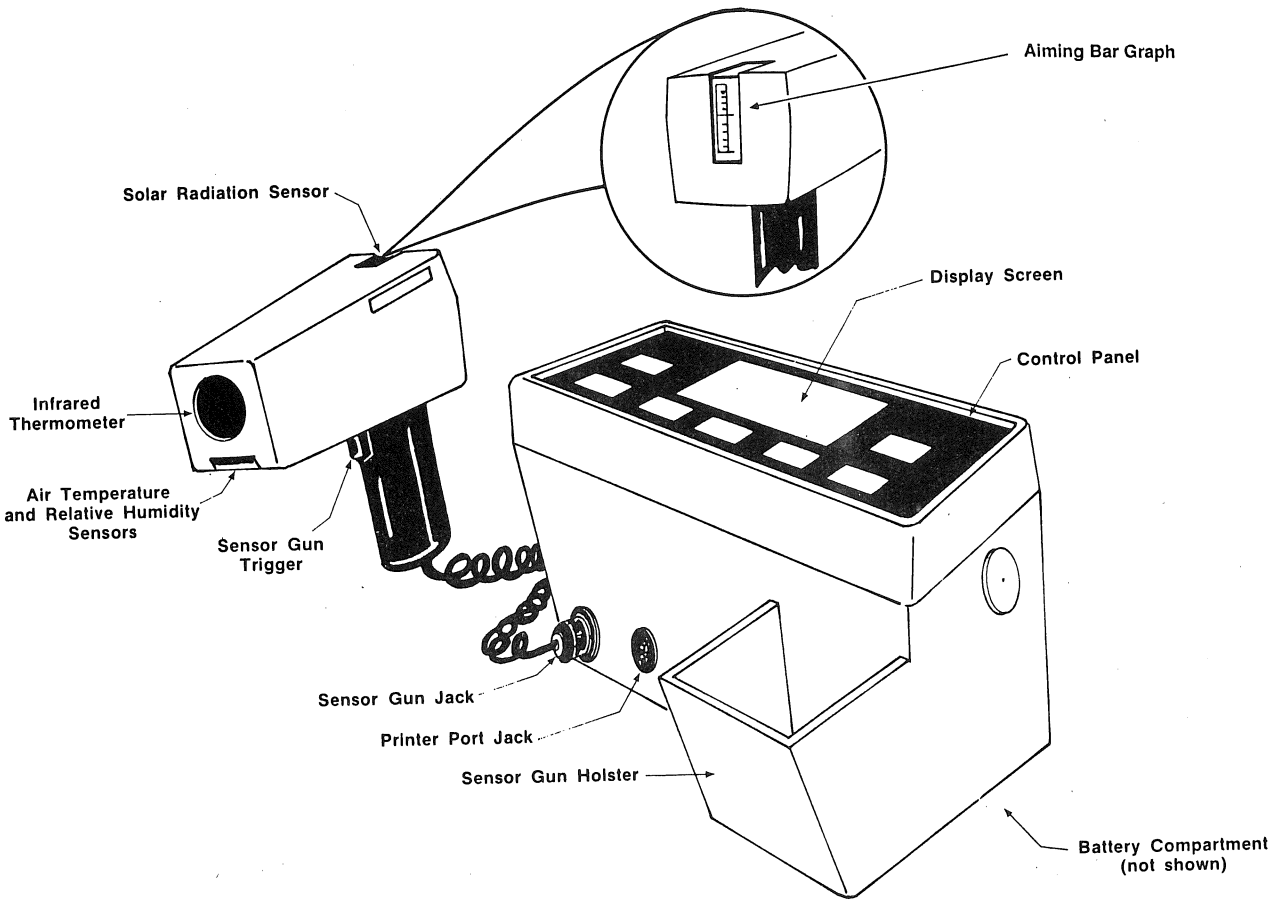
You'll also find practical tips on how to get the most out of your instrument. Before you start, be sure to read the "Meet the Scheduler™" and "What the Scheduler™ Does and General Guidelines for Use" sections.

Manual Outline

- Chapter 1 introduces the Scheduler™'s features and accessories.
- Chapter 2 discusses what the Scheduler™ can do and how to use it in the field.
- Chapter 3 gives operating instructions and shows how to analyze your results.
- Chapter 4 discusses care and maintenance.
- Chapter 5 covers troubleshooting.

1. Meet the Scheduler™

The Scheduler™ combines infrared technology (heat sensing) and environmental measurements to obtain information for irrigation scheduling and other plant monitoring functions. When used properly, the Scheduler™ detects plant stress before visual symptoms develop, thus helping you more confidently manage your crop.



FEATURES

- A sensor package for measuring crop environment and crop canopy temperature. An aiming bar graph improves sampling accuracy.
- A microprocessor unit with control panel and display graphics.
- An external jack for use with printers and other hardware.
- (Optional) A pole for mounting the sensor gun, for taking readings of tall crops.

CROP PACKAGES

The Scheduler™ is designed to determine the crop stress index for specific crops. Each instrument comes with **one** of the following crop packages.

1. Corn, sorghum, alfalfa, wheat, soybeans
2. Corn, sorghum, alfalfa, soybeans, cotton
3. Sugar beets, alfalfa, tomatoes, cotton
4. Turf

Additional packages are being developed and will be available in the future.

Crop Management Easy as 1 2 3

STEP 1 - OPERATION

The Scheduler™ has been designed with the grower in mind. You do not need computer experience; operating the program is as simple as pressing the **ON/OFF** key and following the program commands, or "menus." The **HELP** key takes you to screens available throughout the program, for step-by-step guidance and additional information. Try it--after a few minutes you'll be ready for Step 2.

STEP 2 - SAMPLING

Your plant stress monitor has several features for easy and accurate crop monitoring, or "sampling."

The "What Does the Infrared Thermometer See?" and "General Guidelines for Use" sections of the manual are helpful for fine-tuning your field observations, but keep in mind that experience is the best teacher. By setting the correct field number, crop, date, and time on your Scheduler™, you are ready to begin. Remove the sensor gun from the holster, and follow a few simple guidelines when aiming at your crop target.

- Sample only sunlit portions of the crop.
- Don't sample the soil or the horizon. (The sensor gun sees what you see.)
- Don't shadow the solar radiation sensor.
- Recommended sampling time is from 11:00 a.m. to 4:00 p.m.

You are now ready to examine the world of plant stress. Practice with the Scheduler™ before actually making serious field observations. Look at crops in the field and compare the stress indexes of visibly stressed crops with those of well-watered crops. You'll soon discover previously hidden ranges of plant stress.

STEP 3 - ANALYSIS

The Scheduler™ is a management tool that, coupled with sound management techniques, allows the best managers to become even better. The plant stress index, referred to as 'STRESS INDEX' on your screen, is the measure of the plant's stress status. The 15-day graph plots that point, along with other points from the past 15 days, to give a picture of the field's status and its move away from, or toward, additional water requirements. This status picture can help you anticipate irrigation needs and analyze irrigation or rainfall effectiveness. The dotted horizontal line on the graph warns you when yield-robbing thresholds are approached. Stress indexes consistently above this line may result in yield reductions.

Welcome to the newest technology for plant and irrigation management. The following pages will answer many questions about your new stress monitor.

2. What the Scheduler™ Does and General Guidelines for Use

The Scheduler™ compares the temperature of a plant to its complete environment.

In the field, the Scheduler™ measures the following:

- relative humidity
- air temperature
- plant leaf temperature
- solar radiation load

These measurements are used to calculate the crop stress index, which indicates the degree of stress being experienced by the plant.

CROP STRESS INDEX

Years of extensive research have been devoted to the monitoring of plants. The crop stress index calculated by the Scheduler™ is a product of that research.

Plants, like humans, react differently under different environmental circumstances. The plant's surface temperature is a key indicator of how it's reacting to the local environment, and when this temperature is compared to air temperature, relative humidity, and sunlight level, the Scheduler™ can determine the plant's stress status.

What does the index mean? Index readings of 0 or less indicate a plant is transpiring effectively. Levels above 0 indicate a reduction in the plant's transpiring ability, usually due to lack of available soil moisture. Plants in the 0-0.2 range generally are operating at top efficiency, achieving maximum yield with minimum resources. Research indicates that stress levels **consistently** above 0.2 are subject to quality or yield reduction. Use these values as guidelines for your crop. **Remember that good judgement is always the responsibility of the grower.**

How does the stress index react? Within a few hours of irrigation or rainfall you can expect a reduction in the plant's stress index. However, in some cases this reduction could take a day or longer, especially if the plant was severely stressed. This may be caused by slow water penetration or delays in regrowth of damaged root hairs.

SAMPLING COMPARED TO OTHER METHODS

The Scheduler™ has several advantages over other soil moisture measuring techniques.

- A single measurement can view over 500 times the sample area of a tensiometer, neutron probe, or gypsum block.
- Multiple observations are easy and improve sampling accuracy.
- The instrument is portable.
- Its microprocessing capability lets you store measurements in memory.
- Graphics are quickly produced.

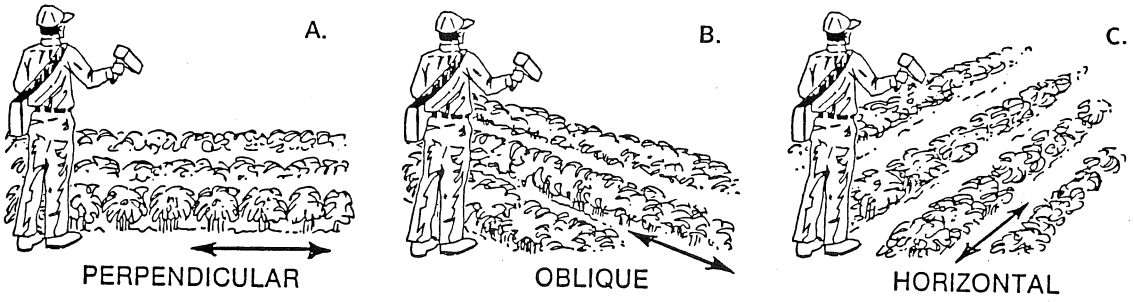
Using the Scheduler™ in conjunction with soil probes or other soil moisture sensing devices will provide new insights into soil moisture levels, reserves, and irrigation timing.

CROP GEOMETRIES

The size and shape of the crop often determine the technique for taking readings.

Generally, readings for row crops should be taken from the sunny side of the plant, with the sun at the viewer's back. Although not as important to some crops, this is a good rule of thumb.

There are several ways to measure a row crop, depending on the sun angle.



A. Across the row(s), perpendicular to row length.

B. Across several rows, at some oblique angle.

C. Down the length of one row. Caution is advised, since crop width is typically much less than row length.

The Scheduler™'s uses will change as a crop matures. The following example gives applications throughout a growing season for corn.

Stage one. Very thin vegetation (1-2 in. wide). It is possible to take stress readings for one plant at a time.

Stage two. Vegetation is 6-12 in. wide. One or two plants may be measured at a time.

Stage three. Mature vegetation (12-24 in. wide). Crop rows can be measured.

Stage four. Very tall crops. Use the optional mounting pole to take readings.

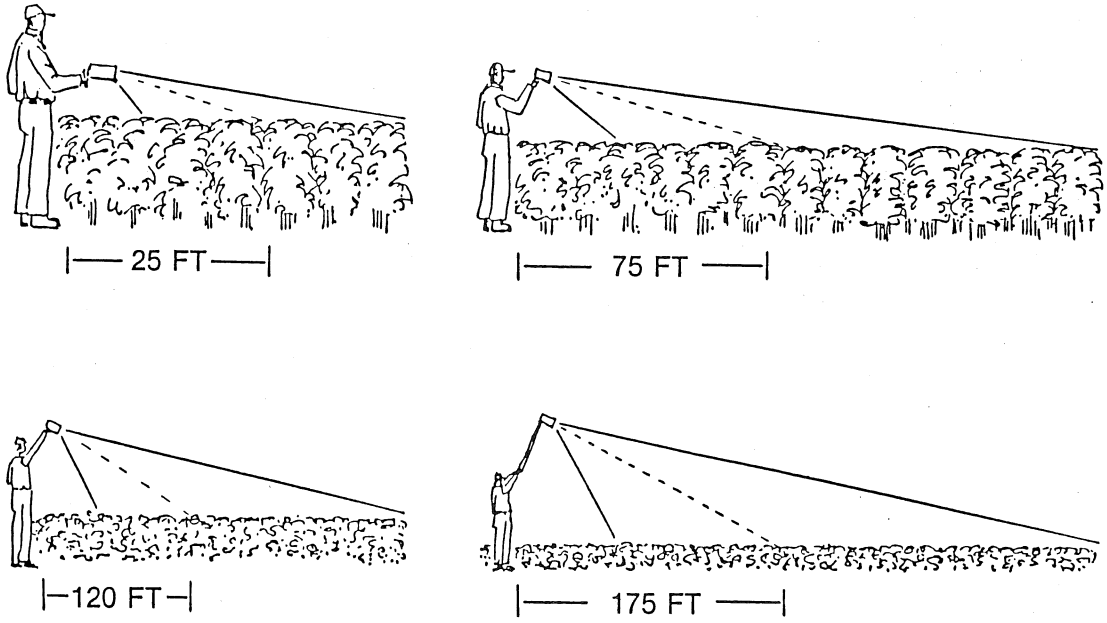
Proper use of the Scheduler™ requires that **only vegetation** be seen by the sensor gun--viewing soil and open sky or other background produces inaccurate readings. If there is any bare soil, take your readings close enough so that only the plant is being examined.

WHAT DOES THE INFRARED THERMOMETER SEE?

You may want to determine what part of the field the Scheduler™ has measured (for example, to locate an area of stress). The area measured by the sensor gun is an oval. In this respect, the field of view is similar to the beam of a flashlight.

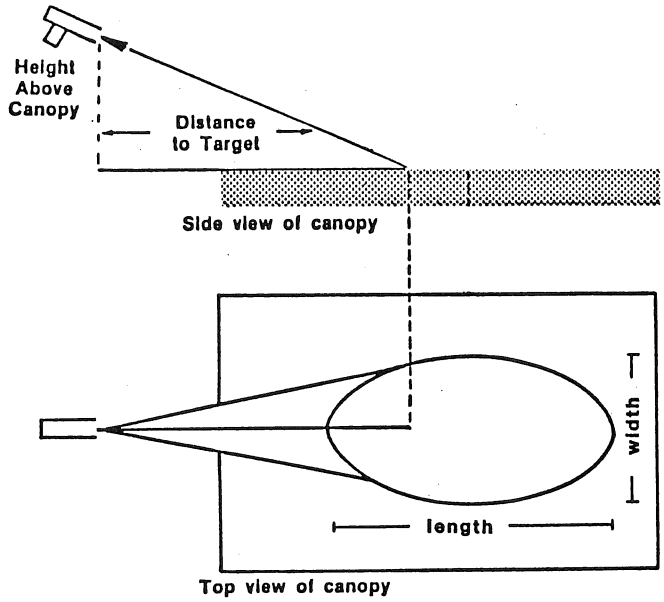
The dimensions of this oval-shaped observation zone are determined by the optics in the infrared thermometer, the height of the sensor gun above the canopy, and the distance to the target.

Use the following guidelines when aiming at the plant target.



- 25 feet should be the limit to your aim when the sensor gun is positioned approximately 1 foot above the canopy.
- 75 feet is the limit at 3 feet above the canopy.
- 120 feet is the limit at 5 feet above the canopy.
- 175 feet is the limit at 10 feet above the canopy.

Table 1 gives sample dimensions for the sensor gun field of view. Field-of-view dimensions are depicted in the accompanying illustration.



Height above Canopy (ft)	Distance to Target (ft)	Oval length (ft)	Max. Oval Width (ft)	Area Viewed (sq ft)
1	1	0.14	0.05	0.01
1	10	8.0	0.4	4.7
1	25	180	1.8	520
3	1	0.2	0.1	0.04
3	10	2.5	0.4	1.5
3	40	48	1.6	120
3	75	550	5.4	4700
5	5	0.7	0.2	0.3
5	50	40	1.9	120
5	120	680	7.7	8200

Table 1. Sample dimensions for the zone "seen" by the sensor gun.

HOW MANY SAMPLES SHOULD I TAKE?

With the Scheduler™, you can collect many samples in only a few minutes. For a good estimate of field conditions, use these guidelines when taking readings:

- For small fields (1-20 acres), take 15 to 20 samples.
- For larger fields up to 160 acres, take at least 20-40 samples.

As a rule, the greater the range of crop canopy temperatures in a field, the more samples you should take.

3. Using the Scheduler™

UNPACKING AND SETUP

The Scheduler™ comes with the following equipment.

- Microprocessor unit with holster compartment for the sensor gun. The detachable instrument strap can be adjusted.
- Sensor gun with attached cable.
- Serial port cable.
- Six C batteries (included).
- Carrying case with quick-reference card.

Do not discard packing materials. They can be used again for any required shipping.

Installing Batteries

Use a screwdriver to remove the two quarter-turn screws securing the battery compartment cover at the bottom of the instrument (refer to diagram, p. 2). Install the six C batteries (the (-) ends should rest against springs). Replace and secure the compartment cover.

Anticipated battery life is 50-60 hours with continuous use (see "Replacing Batteries," p. 26). The pouch in the bottom of the carrying case is for spare batteries.

The Sensor Gun

Connect the sensor gun cable into the outermost jack on the microprocessor unit.

Keep the sensor gun in its holster when not in use. The front end of the sensor gun houses the

relative humidity and air temperature sensors--protect this section from jarring and impact.

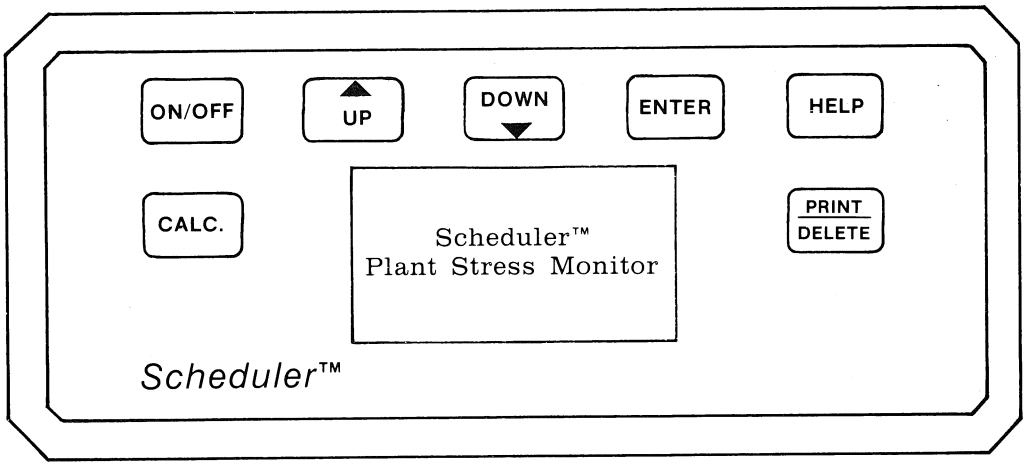
WARMUP

Instruments kept in air-conditioned rooms, storage sheds, vehicles, etc. may be much cooler or hotter than the outside air. When taking the Scheduler™ to the field, allow 5 to 10 minutes to let the sensor package adjust to outside air temperature.

Caution: Do not store the Scheduler™ in places where it will be subjected to extreme heat, such as the dashboard of a vehicle.

KEY FUNCTIONS

Seven multiple-function keys move you through the Scheduler™ program.



ON/OFF - powers the Scheduler™ on and off.

UP,DOWN arrows - allow you to specify field number, date and time, and select the crop option. When indicated on the screen, these arrows are used to move back and forth from screen to screen (scrolling).

ENTER - enters your selections and the sample readings into memory. It also moves you through the program.

HELP - calls up the various Help screens available. Pressing this key again returns you back to the program.

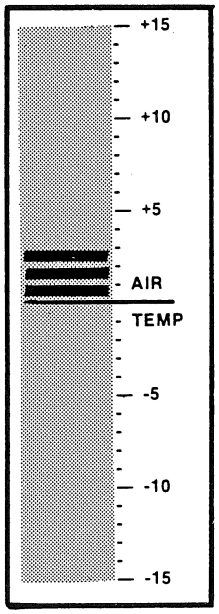
PRINT/DELETE - sends field history to a printer (not included) or deletes it from memory. These key functions are active when identified in the screen text.

CALC. - summarizes field data and summons 15-day graphs and historical records.

SENSOR GUN TRIGGER

The trigger on the sensor gun can be used to record readings during a sampling session. This is its sole function and it is active only when the sensor gun is activated.

AIMING BAR GRAPH



For many crops, leaf temperatures for healthy, transpiring plants are equal to or lower than air temperature.

The air/temp line on the bar graph represents air temperature, and the difference between crop canopy and air temperature appears on the graph as a number of bars. In the illustration, crop canopy temperature is 3 degrees Fahrenheit higher than air. When the difference is greater than ± 15 degrees, the Scheduler™ does not accept the reading and asks you to correct your aim. High readings result when the sensor gun sees soil. If sky is seen, readings are low. For most readings, the difference between crop canopy and air temperature should be within 10 degrees.

The aiming bar graph operates only when you are sampling.

AUDIBLE TONES

When using the Scheduler™, you will hear a series of tones (beeps) that have specific meanings.

- • (one beep) indicates a key has been pressed.
- • • (two beeps) mean that the sensors are powering up.
- • • • (three beeps) indicate a sample reading is being rejected. Consult the display screen for instructions.

GUIDELINES FOR SAMPLING

Follow these rules to ensure proper results.

1. When measuring a row crop, take readings from the sunny side of the plant.
2. Sampling between the hours of 11:00 a.m. and 4:00 p.m. is recommended.
3. The crop should be sunlit during readings. The Scheduler™ works best under full sunlight conditions. If you sample on overcast days, try to take readings at the same sunlight level. On partly cloudy days, the instrument will tell you if the sunlight varies too much. To minimize this effect, take your readings when clouds aren't blocking the sun.
4. Use the instrument in the field. Don't take readings from inside of a truck or building. When taking readings, expose the solar radiation sensor (top, back of gun) to sunlight. It will not operate properly if shadowed.
5. Make sure that only green vegetation is seen by the sensor gun--no bare soil or horizon. For accurate readings, hold the sensor gun 1-3 feet above the crop canopy.
6. Temperature extremes are often found near road surfaces. Avoid taking samples from roadways.

Taking a Reading

The Scheduler™ program is easy to use and cannot be accidentally "ruined" or erased. Each screen lists instructions on what to do next, or what keys can be used at that point. You can make practice sampling runs, which can later be deleted.

Always take the Scheduler™ out of the carrying case when sampling.

Press the **ON/OFF** key. This screen appears.

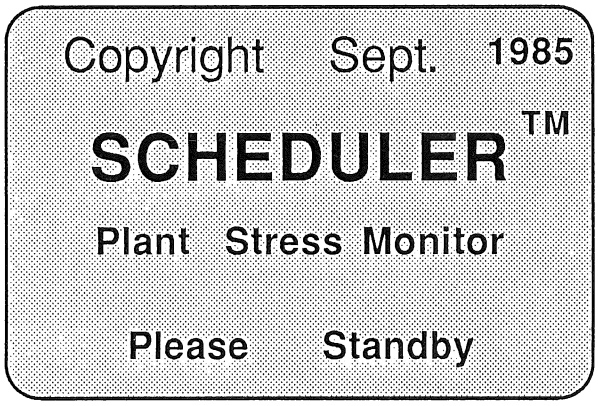


Figure 1. Startup Screen.

MAIN MENU

The Main Menu screen will appear in a few seconds. The Scheduler™ is now ready to use.

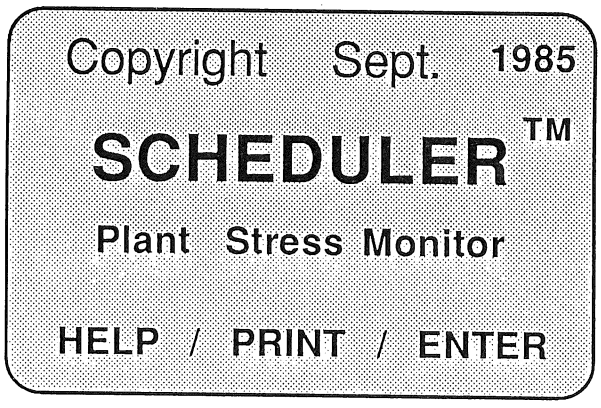


Figure 2. Main Menu Screen.

HELP FUNCTION

By pressing **HELP**, you get a screen listing key functions for the program. To exit from Help, press **HELP** again (note that this feature applies to all Help screens). The following is one of the Help screens available.

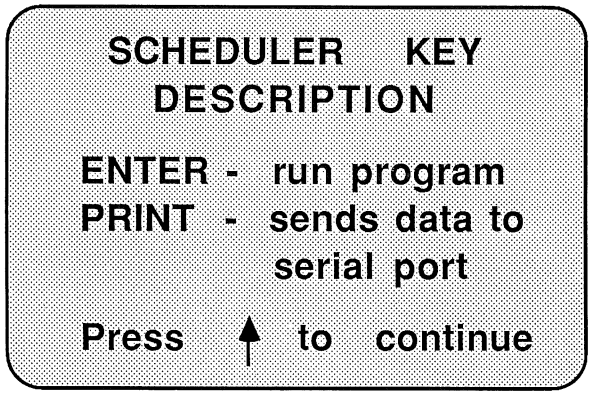


Figure 3. Help Screen from Main Menu.

FIELD SELECTION SCREEN

Press **ENTER** to begin the program.

An inverse-video (backlit) image indicates which item (FIELD, CROP, DATE, TIME) is being entered ('FIELD' in the example below). Where it applies, crop stage (01 for pre-head, 02 for post-head for wheat) is also listed.

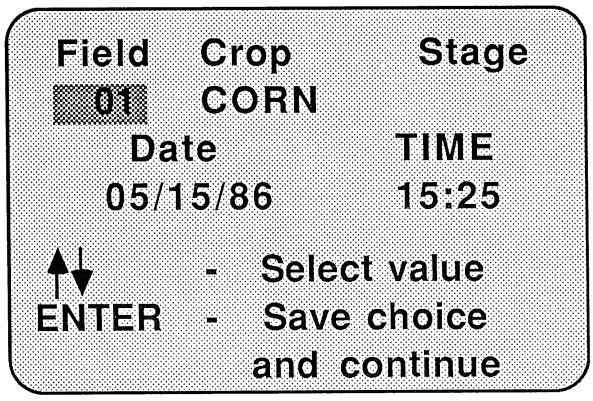


Figure 4. Field Selection Screen.

Pressing **ENTER** saves your choice and moves you to next item. To change a selection, use the **UP**

arrow and **DOWN arrow** keys to scroll to other values. (Using this feature is similar to setting time on a digital watch.) The date is entered as month/day/year, the time as hours:minutes in marine time (for example, 3:25 p.m. is 15:25). The 24-hour internal clock in the Scheduler™ will automatically track date and time.

If you make a mistake or want to change a selection, pressing **PRINT/DEL** moves you back one item each time and lets you try again. A Help screen is available.

After you have entered your information, a screen will inform you

> 'Press ENTER to begin sampling. Press CALC to review field history.'

Refer to "Reviewing Historical Data," p. 23, if you want to review a field history.

Press **ENTER** to activate the sensor package.

TAKING THE SAMPLE

The sensors in the sensor gun are now active. Briefly, a message screen ('SENSORS POWERING UP') appears. The Taking Samples screen follows.

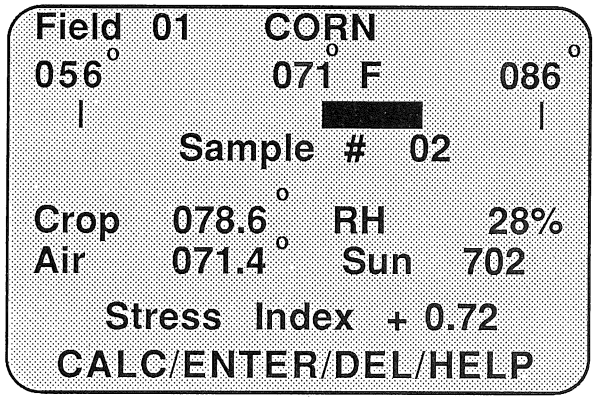


Figure 5. Taking Samples Screen.

Aim the sensor gun and record your reading by either pressing the trigger on the sensor gun or by pressing the **ENTER** key on the microprocessor unit.

The message, '**TAKING SAMPLE**', appears briefly at the top of the screen, and the sample number advances automatically.

All temperature readings in the program are in degrees Fahrenheit. Solar radiation ('Sun') readings are in watts per square meter (W/m^2).

The Scheduler™ detects unsuitable readings and gives you a message screen (see "Rejected Readings," p. 28).

The aiming bar graph on the screen functions the same way as the one on the sensor gun (see "Aiming Bar Graph," p. 14). The Scheduler™ won't accept readings that exceed the outdoor temperature by ±15 degrees Fahrenheit. A cursor flashes at either end of the bar graph and a screen tells you if the reading is too hot or too cold. Press **ENTER** to return to the Taking Samples screen.

It is important that you delete an unwanted reading before taking any more samples. Press **PRINT/DEL** to delete your most recent sample. **You cannot delete individual readings later in the program.**

Automatic Timeout

The automatic shut-off feature conserves battery power. If no keys are pressed for 10 minutes, the Scheduler™ turns itself off. If the Scheduler™ has shut off and you want to use the samples you had taken, you can review the field history. Your samples have been automatically averaged and calculated. If you want to sample the field again, your old readings will be erased (see "Returning to the Same Field for Sampling," p. 22).

Analyzing Results

The Scheduler™ stores information for 30 fields, with up to 99 samples per field.

Press **CALC** when you have finished sampling a field. The Field Summary screen follows.

FIELD SUMMARY

The Scheduler™ automatically records and averages sample readings. Good sampling techniques will yield calculated averages that represent your crop.

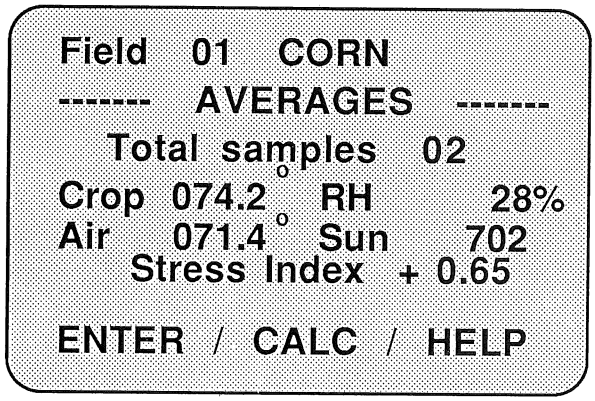


Figure 6. Field Summary Screen.

The values for Crop, Air, RH, and Sun are averages of sample readings for a field or sample area. The stress index for the field summary is adjusted to be representative of field conditions. It is not an average of all crop stress indexes, but is calculated using the averages of all the measurements (the numbers on the Field Summary screen).

At this point, you have two options. To sample another field, press **ENTER** to return to the Field Selection screen. To view the graph of field summary stress indexes from the past 15 days, press **CALC**.

THE 15-DAY HISTORICAL GRAPH

The graphics capabilities of the Scheduler™ allow you to monitor stress index trends, analyze irrigation effectiveness, and project irrigation requirements.

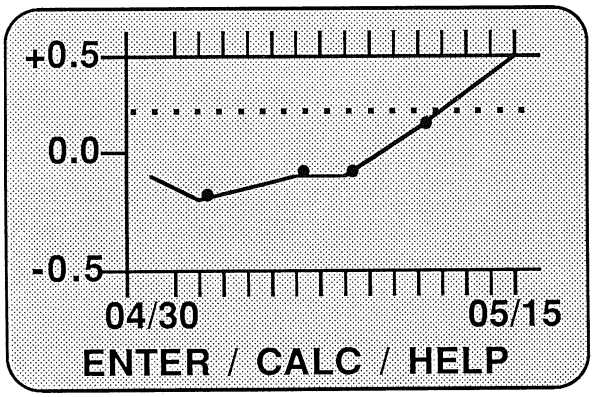


Figure 7. 15-Day Graph Screen.

The past 15 days are depicted, with the current date furthest right. In the example, which uses the field summary of Figure 6, data was collected for 5 of the past 15 days. The graph has only 4 data points because one of the stress indexes (+0.65) plots outside graph boundaries.

If the sampling day is overcast, the Scheduler™ accounts for it when determining the stress index. When solar radiation ('Sun') is below 450 W/m^2, a low-sunlight indicator is used on the screen. Hollow points signify cloudy conditions, solid points indicate high sunlight levels. This is a useful feature when analyzing stress trends.

Research indicates that yield reductions may occur if the stress index is consistently above the horizontal line.

At this point in the program, you have two options. To sample another field, press **ENTER**. To get a screen listing these stress index values, press **CALC**.

THE 15-DAY HISTORICAL TABLE

The past 15 days of historical data are listed on this screen. Use the **UP arrow** and **DOWN arrow** keys to scroll through this listing.

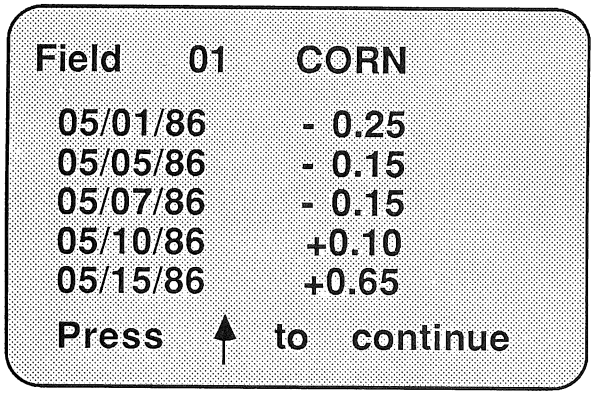


Figure 8. 15-Day Historical Table Screen.

To sample another field, press **ENTER**.

RETURNING TO THE SAME FIELD FOR SAMPLING

The Scheduler™ prevents you from accidentally re-sampling the same field.

To re-sample a field the same day, select your field number at the Field Selection screen. At the screen following Field Selection, specify that you want to take samples by pressing **ENTER**. The following screen appears.

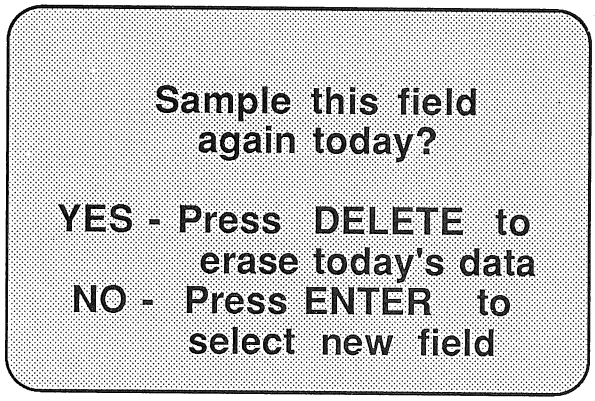


Figure 9. Re-Sample Field Screen.

Press **PRINT/DEL** for 'yes'. Any data gathered earlier that day is erased and you are returned to

the Taking Samples screen. If you press **ENTER** for 'no', you keep the data and are returned to the Field Selection screen.

Other Program Features

REVIEWING HISTORICAL DATA

At any time, the Scheduler™ allows you to review the records of the past 15 sampling days. At the Field Selection screen (Figure 4), select the field number that you want to review. Press **ENTER** to verify the other entries on the screen. When the screen prompts you, press **CALC** to view historical data.

If you have sampled the field that day. You will get a Field Summary screen.

If you have not sampled the field. You will get the 15-day historical graph for that field.

USING A PRINTER

The Scheduler™ prints today's sampling results or historical records from the past 15 days. Your printer must be able to handle an 80-column format.

On printouts for daily sampling results, the following items are listed for each field:

- Field number, crop, crop stage, and time (space is allotted for 30 fields).
- Averages for crop temperature, air temperature, relative humidity, and solar radiation.
- Adjusted stress index.
- Number of samples taken.

On printouts of 15-day historical records, the following items are listed for each field:

- Field number
- Date
- Stress index
- Day type (cloudy or sunny)

To select the Print option, press **PRINT/DEL** at the Main Menu screen (Figure 2). To get to the Main Menu you need turn the instrument off, then on (**ON/OFF** key).

After you specify the type of printout (daily sampling results or 15-day historical record), the program advances to the Print Configuration screen, where you configure the serial port. If you are using an Epson FX80 printer, configure both the printer and Scheduler™ as follows.

1200 baud
7 bits/character
2 stop bits
no parity
DTR protocol

Other configurations are available.

The Print Mode screen appears and requests you to connect the hardware. The Scheduler™ comes with a standard RS232 serial port. Connect the cable to the printer port jack (see diagram, p. 2).

Press **PRINT/DEL** to begin sending data to your printer. Press **ENTER** to interrupt printing.

ERASING 15-DAY RECORDS

To delete 15-day records you no longer want to keep, you need to select the Print option on the Main Menu screen (press **PRINT/DEL**).

To erase memory, press **ENTER** to get out of the Print Configuration screen and into the Print Mode screen. Press **PRINT** (as if you are connecting a serial port to a printer). A screen with the message

'SENDING DATA TO THE RS232 PORT. PLEASE STANDBY.'

appears briefly, to be replaced by

'DO YOU WANT TO ERASE MEMORY?'

PRINT/DEL erases field records from the past 15 days. Press **ENTER** if you do not want to erase (you are returned to the Main Menu).

4. Maintenance

CARE AND CLEANING OF SENSORS

Avoid exposing the sensors to contaminants such as cigarette smoke, oils, and gasoline fumes.

The relative humidity and air temperature sensors are housed in the forward nose compartment of the sensor gun. **Do not get water on this part of the pistol. Wetting can damage the relative humidity sensor.**

If the lens of the infrared thermometer requires cleaning, use a cotton swab wetted with ethanol. The alcohol must not have denaturing additives; these will leave a residue. Remove minor accumulations of dust with a camel's hair brush.

The plastic window protecting the solar radiation sensor can be cleaned with lens paper or a camel's hair brush (available at photography and art supply departments). More stubborn debris can wiped off with a slightly dampened cloth and mild detergent. Again, take care not to get any water droplets into the gun.

REPLACING BATTERIES

The Scheduler™ requires six C-size batteries. Alkaline batteries provide the longest life (estimated 50 hours of continuous use). Zinc or rechargeable nickel-cadmium batteries can also be used, but require more frequent replacement, or recharging. Zinc battery life is estimated to be 25 hours. Nickel-cadmium batteries should be recharged after 10 hours.

Remove batteries before prolonged storage to avoid damage from leaking corrosives. The Scheduler™ is equipped with an internal lithium cell for powering the clock and protecting stored data. This cell has a minimum functional life of 8 years.

RESETTING CLOCK

The Scheduler™ clock accounts for leap years. However, changes in time zone or switching to

daylight savings time require resetting the clock. Reset the clock through the Field Selection screen (see "Field Summary," p. 20).

5. Troubleshooting

REJECTED READINGS

The Scheduler™ gives a message when it detects something is wrong with a reading.

'Sunlight Varying Too Much'

The Scheduler™'s effectiveness is highly sensitive to light conditions. On partly cloudy days, sampling when the sun is not blocked by clouds will give good results. On very cloudy days, defer sampling to days of higher sunlight level.

'Target Temperature Out of Range--Correct Sensor Aim'

This message appears when the aiming bar graph is indicating target temperatures that are too hot (cursor flashes at the right end of the bar) or too cold (cursor flashes at left).

Pressing **ENTER** at either of the above screens returns you to the previous (Taking Samples) screen, where you may try entering the sample again, or you can end the sampling session (press **CALC** to summarize field samples and store the data).

LOW BATTERIES

The Scheduler™ tells you when batteries are failing (see "Replacing Batteries," p. 26). When you enter your sample information at the Field Selection screen, a warning screen will appear. Replace the batteries before doing any more sampling.

SERVICE AND REPAIR

If your your instrument requires service, contact your local dealer or address your inquiries to the following address:

Standard Oil Engineered Materials Company
4440 Warrensville Center Rd.
Cleveland, OH 44128

c/o Steven C. DeSutter

Ph. 216-581-5538

SCHEDULER™
PRODUCT REGISTRATION

Enclosed is a removable Product Registration Card which we ask that you complete and send to:

Standard Oil Engineered Materials Co.
4440 Warrensville Center Rd.
Cleveland, OH 44128

IMPORTANT! Return of this card is important to insure this Product receives proper post-sale service.

We have provided you space to record the date of purchase and name of your retailer for your convenience.

Owner _____

Street _____

City/State _____

Zip Code _____

Dealer _____

Date Purchased _____

Serial No. _____

ONE YEAR LIMITED WARRANTY

Seller warrants Scheduler™ to be free from defects in material and workmanship under normal use and conditions for a period of one year from date of purchase. In the event service should be necessary for any reason due to manufacturing defect or malfunction during the warranty period Seller will repair or replace at its discretion, the defective Scheduler™ at no charge (except for a small charge for handling, packing, return postage, and insurance), upon delivery of the Scheduler™ to Standard Oil Engineered Materials Co., 4440 Warrensville Rd., Cleveland, OH 44128, along with a copy of proof of purchase date. This warranty is valid only in the United States of America and does not extend to owners of this product subsequent to the original purchaser. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS, IMPLIED OR STATUTORY AND DOES NOT INCLUDE ANY WARRANTY OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE. UNDER NO CIRCUMSTANCES SHALL SELLER BE LIABLE FOR ANY LOSS OR DAMAGE, DIRECT, INCIDENTAL OR CONSEQUENTIAL SUCH AS BUT NOT LIMITED TO, CROP DAMAGE, ARISING OUT OF THE USE OF, OR INABILITY TO USE THE SCHEDULER™. THIS WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH MAY VARY FROM STATE TO STATE.

STANDARD OIL
ENGINEERED MATERIALS COMPANY
P. O. Box 391316
Solon, Ohio 44139
(216) 349-6881

SCHEDULER® Plant Stress Monitor

Technical/Training Manual

Copyright February, 1988

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CARRYING CASE
CONTROL PANEL
& DISPLAY SCREEN
BATTERY POUCH
PRINTER CABLE
SENSOR GUN HOLSTER
BATTERY COVER
PRINTER PORT JACK
SENSOR GUN
SENSOR GUN JACK
RESET BUTTON
INFRARED THERMOMETER
AIR TEMPERATURE
& RELATIVE HUMIDITY SENSORS
SOLAR RADIATION SENSOR
TEMPERATURE BAR GRAPH

SCHEDULER^{R} PLANT STRESS MONITOR

TRAINING AND TECHNICAL MANUAL

CHAPTER 1

INTRODUCTION

1.1 Purpose of the Scheduler^{R} Plant Stress Monitor

Plants, like humans react to their environment. Plant temperature is the key indicator of how a plant is reacting. The Scheduler^{R} Plant Stress Monitor contains an index based on plant temperature which allows you to make an accurate determination of stress status and make management decisions based on plant condition. The plant stress index allows you to detect stress before visual symptoms develop. The result is a new technology that allows the grower to produce healthier crops, and often obtain a savings in water, fuel and labor.

1.2 Theoretical Summary

Plant leaves contain small openings similar to the pores on human skin. When these pores, called stomates, are open, leaves evaporate water at a rate which is controlled by the properties of the surrounding air and the intensity of the impinging sunlight. Several factors cause stomates to close: water stress, disease and insect damage are three significant factors. When the stomates start to close, if the sunlight is sufficiently intense, a leave will evaporate water at a lower rate than a leaf with open stomates. The tighter the stomates close, the slower the evaporation rate from the leaf. The result is that a leaf with closed stomates will be hotter than a leaf with open stomates. This hotter leaf temperature can then be detected with infrared technology and, when combined with a specific crop model, can be converted to a stress index.

1.3 Historical Summary

The first evidence that water-stressed plants are warmer than well-watered plants was reported in 1843, with

the aid of mercury thermometers. The second report on this phenomenon was made in 1875. Although the phenomenon was well documented, it was evident that mercury thermometers were simply not a practical tool. Beyond that, theory to explain the phenomenon could not be identified. By 1923, the USDA had begun to use crude thermocouples to study the effect of water stress on plant temperatures. These studies revealed important correlations for a large number of plant types. These studies were interruped by World War II. The scientists of that era developed several conflicting theoretical explanations.

In the early 1950's, the USDA and several universities again began studying the phenomenon. By this time, it had been realized that crop yields and quality are affected by mild water stress and that temperature stress was important to monitor. A comprehensive theory, which was based on heat transfer and aerodynamic principles, was proposed. Portable instrumentation did not exist to test this theory. In the 1960's, the military declassified a relatively crude infrared thermometer. Some university researchers began using the tool in the field to study crops, but the high cost and technical operating difficulties limited its use.

In the mid 1970's, a relatively inexpensive and reliable infrared thermometer became available. Several university and USDA agencies began researching the application of this tool for agricultural crops, both in stress detection and yield monitoring. By 1980, a few researchers had effectively demonstrated the application of these theories to scheduling irrigations in corn and monitoring yield losses in wheat, corn, alfalfa and sorghum. Between 1980 and 1984, theories were developed which finally allowed a stress researcher in one part of the country to compare his work with that taking place in another area. The theoretical basis for irrigation using infrared thermometers was established and several scientists were urging its use.

In 1984, Standard Oil of Ohio became involved in the advancement of this technology and funded tests to validate the theories. Although the market aspects were not fully understood, it was believed to be a powerful new tool for the agricultural industry. In 1985, large scale tests of the technology were conducted by Standard Oil, which clearly demonstrated the effectiveness of the technology. In addition, these tests also identified several opportunities for growers to benefit from the use of this technology. During 1986 and 1987, the technology was validated on over two dozen major agricultural crops, including cotton, grapes, melons and turf.

It is important to note that in all these crops, irrigation scheduling is only one application of this technology. In addition, infrared technology can be used to assess the uniformity of an irrigation system, thereby offering an irrigator a tool with which to "fine tune" his system. Controlling stress levels and disease detection are other important applications.

CHAPTER 2

THE STRESS INDEX AND FIELD USE

2.1 Leaves

When people get sick, their temperature rises above 98.6°F. The higher the temperature, the more serious the sickness. When plants are thirsty, or sick, their transpiration rate is lower than it should be. The result is a plant that is hotter than it should be. By measuring leaf temperatures and the environment, direct feedback from the plants can be translated into a form which is useful for management purposes. (Figures 1 and 2)

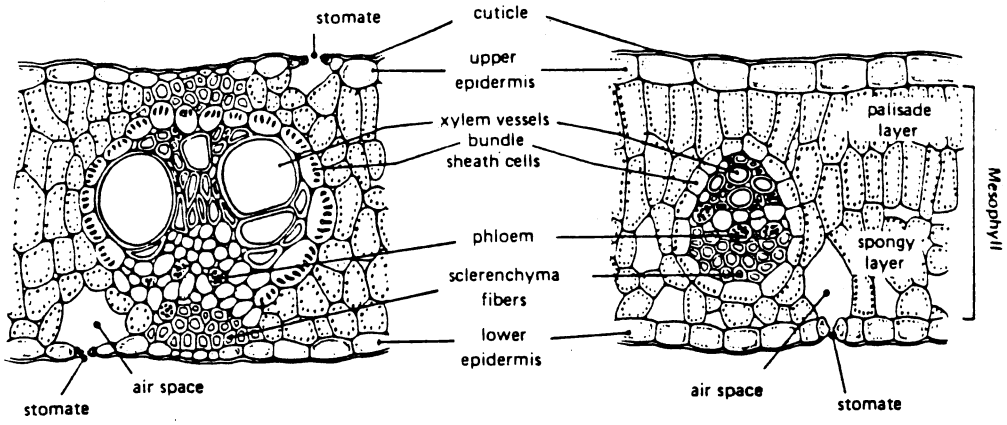


Diagram of the cross section of a monocot and a dicot leaf. [From R. H. Arnett, Jr., and D. C. Braungart: *An Introduction to Plant Biology,* 3rd ed. The C. V. Mosby Co., St. Louis, 1970.

Figure 1

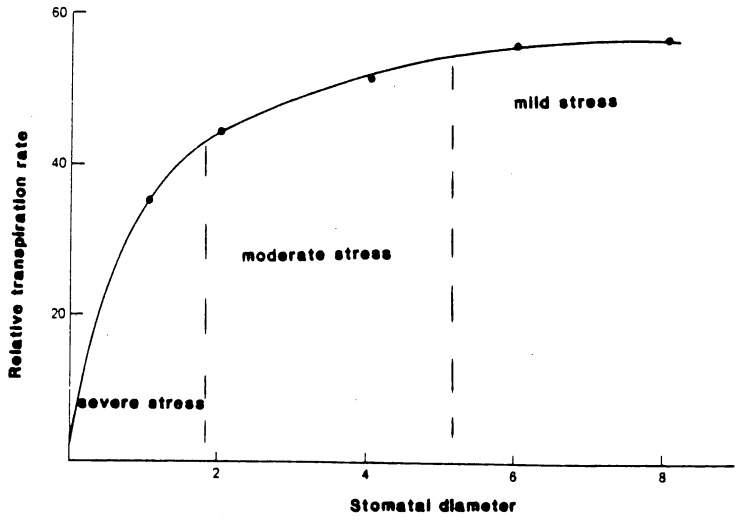


Figure 2

2.2 Stomata

Small pores on the surface of leaves (stomata) give a leaf the ability to regulate the rate at which carbon dioxide and water vapor move into, and out of, the leaf. Stomata are generally open in the day and closed at night. Stress (water, disease, insect) will cause stomata to close during the day. When the sun is shining brightly, a leaf with closed stomata will be hotter than a leaf with open stomata. (Figure 3)

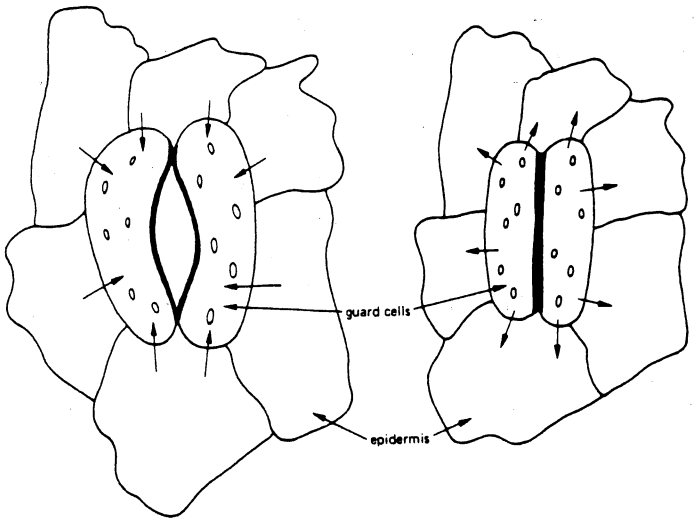


Diagram of a stomate. Arrows show direction of water movement.

Figure 3

2.3 Stress Index

In 1982, the USDA proposed a plant stress index known as the Crop Water Stress Index (CWSI) (Jackson, 1982). This index was based on an extensive review of the science relating to leaf temperatures, and on field research conducted by the USDA since the 1920s.

The results of these USDA studies show that there is a strong correlation between the evironmental parameters of air temperature, relative humidity, and sunlight with leaf temperatures for each plant species.

Although it has been possible to measure the separate components of CWSI since the mid 1970s, no instrument existed which could automatically measure all the parameters and provide answers in the field until the Scheduler^{R} Plant Stress Monitor was developed in 1984.

Since 1984, Standard Oil researchers have learned a great deal about the practicalities of using CWSI. Standard Oil has become the leader in understanding the theory and practical usage of this powerful index. Proprietary adjustments to the theory have been included in the Scheduler which allow the index to perform well in all agricultural areas.

2.4 The Drying Power of the Air

At a given temperature, moisture saturated air holds a known weight of water. In the field, the air is generally not saturated. The difference between the weight of water air can hold and the amount of water it does hold is known as the vapor pressure deficit. As the vapor pressure deficit increases, the drying power of the air increases. The drying power of the air is the ability of air to evaporate water (from a leaf or any other surface). The stronger the drying power of the air, the greater the transpiration of water from a leaf surface. This, in turn, lowers the leaf temperature because of the cooling effect of transpiration. The drying power of the air not only controls leaf temperature, but also controls the rate at which diseases develop.

2.5 Factors Which Affect Index Values

The Scheduler measures the four parameters of Air Temperature, Relative Humidity, Solar Radiation and Crop Canopy Temperature from which it calculates a plant stress index (PSI). This crop-specific index (or crop model) is a statistical representation of how a specific crop type will react to the heat load placed on it from its growing environment in both stressed and non-stressed conditions.

The index theoretically ranges between 0 and 10. In the field, it is common to see values ranging from -2 to 10. The following factors have differing effects on the plant stress index:

1. Clouds have a major effect on index values. When a cloud moves in front of the sun, the index decreases rapidly. To avoid confusion, we recommend using the index only when the sun is shining brightly on the target area. Under cloudy conditions, the index on well-irrigated areas may go as low as -10. (Figure 4)

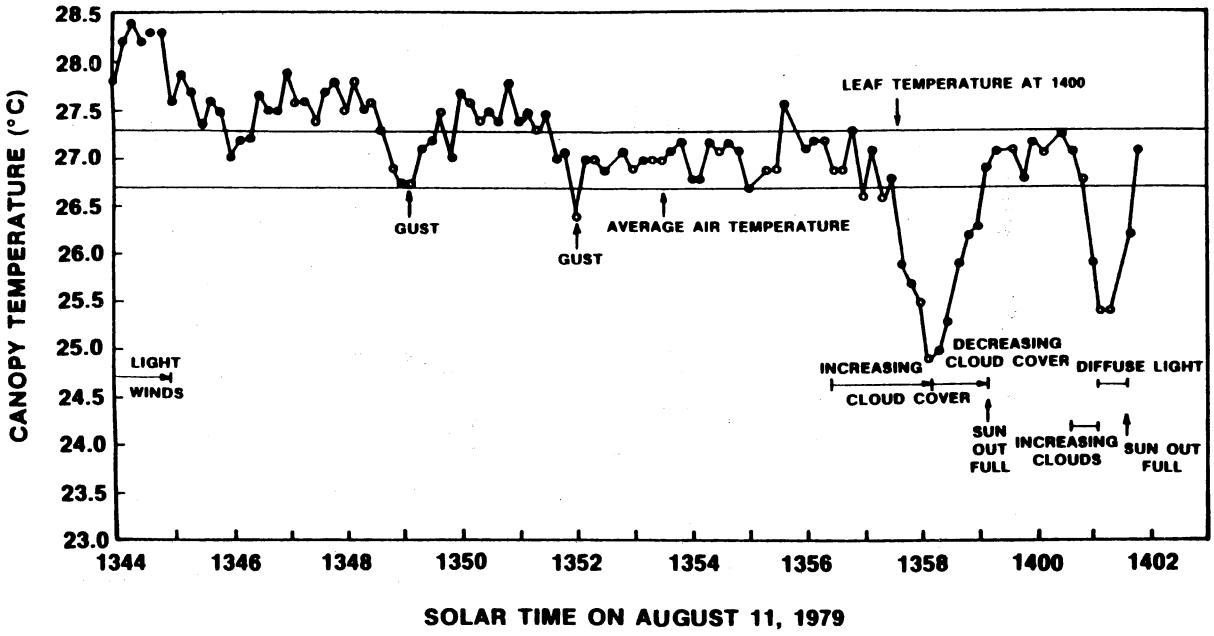


Figure 4

2. Windspeed. Wind has a minor effect on the index. (Figure 5)

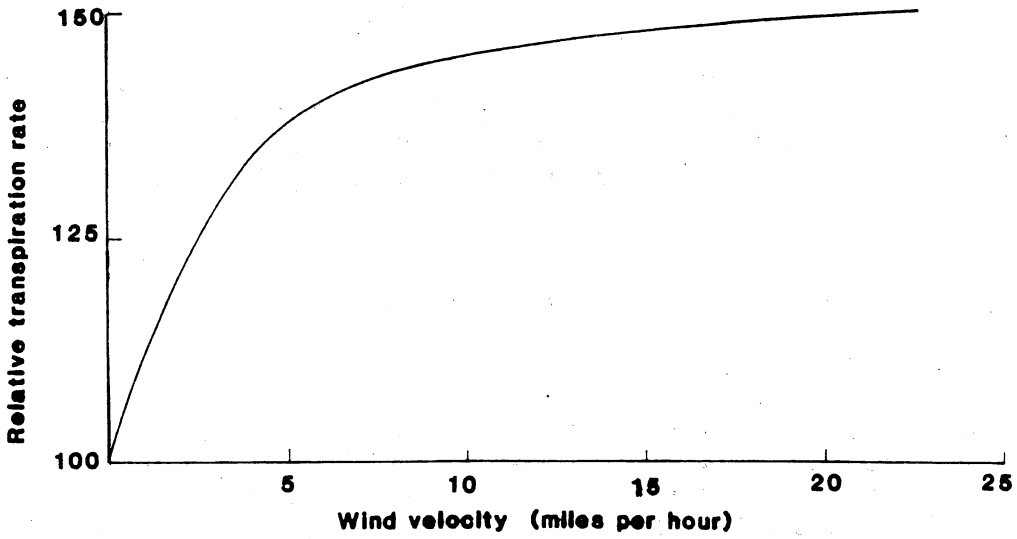
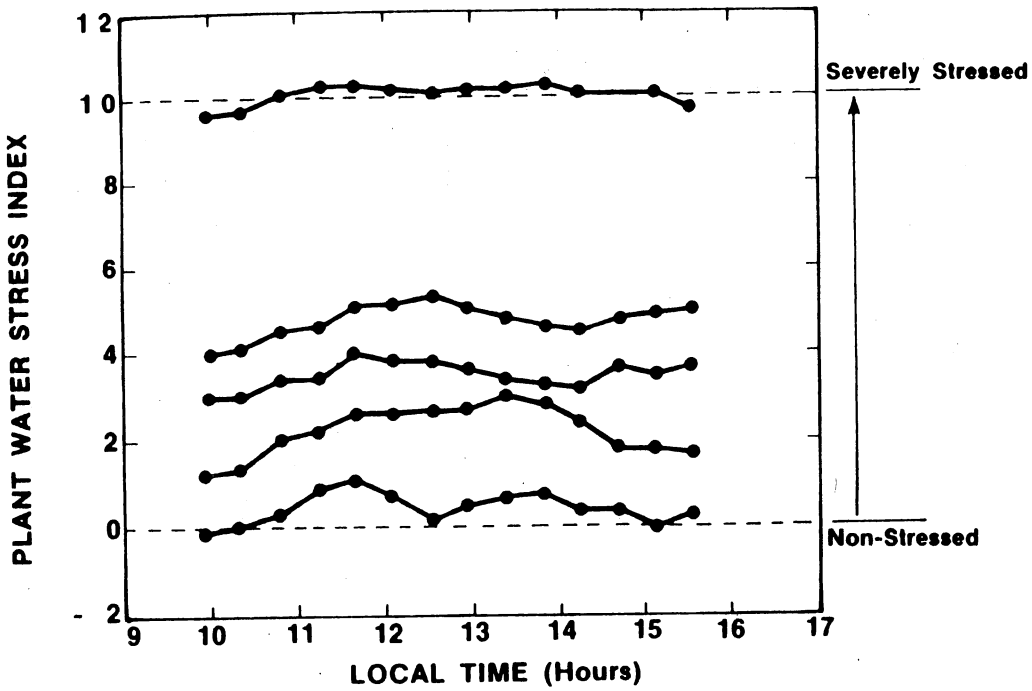


Figure 5

3. Time of day. The index changes only slightly between 11 AM and 4 PM but undergoes major changes outside of these limits. (Figure 6)



Plant water stress index as a function of time for five differently stressed plots of alfalfa at Phoenix, Arizona on Speptember 17, 1980.

Figure 6

4. Air temperature. The index for a crop is defined for normal growing conditions. When the air temperature becomes much cooler than normal, the index will decrease, reducing the effectiveness of the index.

2.6 Interpreting the Plant Stress Index

Each unit increase in the Plant Stress Index corresponds to approximately a 10% decrease in the transpiration rate. For example, if one area has an index of 1.2 and a second area has an index of 3.2, then the second area is transpiring water about 20% slower than the first area.

General Index Interpretations

< 0	No stress: (usually optimum yields)
0-2	Minimal stress: (usually no effect on yields or quality)
2-5	Moderate stress: (sustained readings in this range reduce yields and quality)
5-8	High stress: (sustained readings cause visual symptoms)
8-10	Extreme stress: (plant is in extremely poor conditon)

General Index Patterns

The index usually cycles between no stress and moderate stess values between irrigations. It is common to see an increase of 1-2 stress units after an irrigation. This pattern is caused by lack of oxygen, especially in heavy soils caused by saturation of the soil profile. As drainage occurs, there is a rapid decrease in the index. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall. Overcast skies, clouds, or cool weather cause a temporary decrease in index values.

In row crops, it is typical for index values to be moderate early in the season. As the roots grow deeper and leaf area increases, the index value becomes progressively lower. During the major portion of the season, the index should cycle from no stress to moderate stress index values between irrigations. Late in the season, as the leaves dry, the index will gradually increase to moderate levels.

Yield/Quality Relationships

In general, the cooler a crop stays, the higher the yields and the better the quality. In applications where stress is desired, the use of the index insures the stress levels remain under control.

2.7 Using the Scheduler in the Field

Several factors can affect the index. Experience, consistency of use, proper aiming technique and effective data analysis are the keys to getting good results.

For best results, remember the following guidelines:

1. Stage of growth. Young plants, especially in row crops, have higher index values than large plants. This is normal. For example, a young cotton plant may have minimum index values of 2.0, but a mature cotton plant has minimum index values less than 0.

2. Target area. Imagine for a moment that the sensor gun is a flashlight. The area illuminated by this flashlight depends on where you aim it. This is also true of the sensor gun. Although you aim the Scheduler like a gun, the area measured is seen like a flashlight. Remember, if your eye can see soil, so can the Scheduler. It must see crop canopy to be accurate.

3. The best readings are made when the sunlight is bright and stable on the crop.

4. Take samples between 11 AM and 4 PM in the summer growing season, and between 1 PM and 3 PM in the winter growing season.

5. Take at least 30 samples in the field. Try to include readings from at least 3 separate areas.

6. If you leave the Scheduler in a hot truck , or a cold office, it will take a little time to adjust to the field environment. The Scheduler works best when the hardware temperature is reasonably close to ambient conditions in the field.

7. Keep the sensor gun at least 3 feet above the soil. Sampling the air temperature near the soil will invalidate the index.

8. Plants must be dry and free from dew.

9. The user must be in the field. You cannot take readings from pick-up windows since air temperatures around vehicles, roads or access lanes are often different than in the field.

10. Always keep the sun at your back.

2.8 Simple Operating Instructions

Turn the Scheduler on properly.

1. Step out of the truck.
2. Remove the Scheduler from its case.
3. Remove the sensor gun from its holster.
4. Turn the Scheduler on, keeping the gun out of its holster.
5. During the 94 second count-down, walk to your target area.
6. Before taking your first sample, watch the air temperature reading. It should be stable (not increasing or decreasing).
7. If the sensor gun case feels very hot (or very cool), let it adjust for a few more minutes before taking your first sample. Remember, the Scheduler works fast anyway. Waiting a minute or two for it to adjust to the field environment will insure accuracy and is well worth the wait.

For a complete explanation, refer to the owners' operating manual.

CHAPTER 3

COMPARING THE SCHEDULER^{R} PLANT STRESS MONITOR TO OTHER METHODS

3.1 Pressure Bomb Comparison to the Scheduler^{R} Plant Stress Monitor

The general relationship between pressure bomb readings and Scheduler^{R} Plant Stress Monitor stress index readings is linear (Figure 7) according to research conducted by the University of California. This research also shows that users should not try to develop their own correlations between Scheduler and pressure bomb readings. Two reasons for this include differences in the scale of measurement (single leaf vs. whole canopy) and sampling differences (minutes for pressure vs. seconds for the Scheduler).

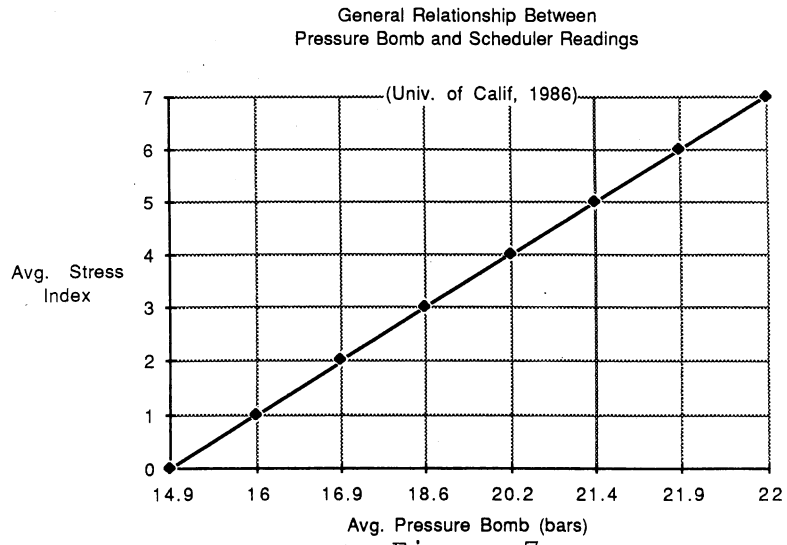


Figure 7

3.2 Soil Moisture

In general, there is a very high correlation between soil moisture deficits and index readings. As index readings increase, soil moisture deficits become larger. Use of the Scheduler with good soil moisture programs will give the grower a better picture of both soil depletion and its effect on the growing plant, providing superior inputs to irrigation scheduling.

3.3 Statistical Benefits

Growers need to realize that all management techniques such as sampling soil moisture, sampling leaf water potential with pressure bombs or sampling stress index values are statistical processes. In a sense, modern farm management essentially treats a farm as a commercial-scale experiment. Attempts are made at repeating the treatments and therefore, achieving top economic results year after year. Statistics play a vital role in effective farm management, whether they are used knowingly or not by the grower.

The Scheduler can collect and process 17 samples in less than one minute and 86 samples in five minutes. Each sample will incorporate the behavior of hundreds of plants. The Scheduler is the only plant stress analysis tool capable of providing a grower with the volume of sampling required for statistical accuracy.

CHAPTER 4

GUIDELINES FOR SPECIFIC CROPS

4.1 Index Values

There are two ways of summarizing index information. One way is to use the season-long average. This number is important, but can sometimes be misleading. For example, an average index of 1.0 can be achieved by irrigating a crop so that its index varies only slightly on either side of 1.0. A crop can also be irrigated so that the index cycles between -2 and +3 between irrigations. In both cases, the average index is the same.

The season average index values for most plants are typically 2 or less, but crops differ significantly in the range of the index values between irrigations. The range of index values which is best is dependent on the crop and on the stage of growth.

4.2 Young Plants

The normal expected stress index for young plants is higher than more mature plants. For example, a stress index of 4 or 5 at 40% ground cover would be normal for young plants, but would indicate stress at 100% ground cover.

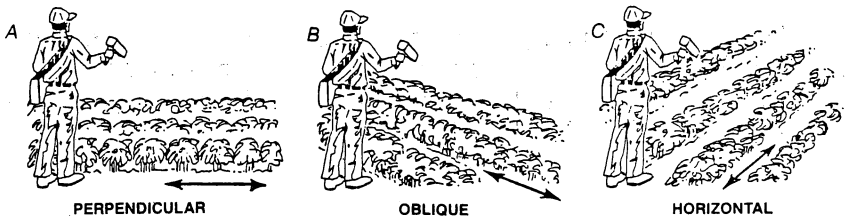
1. Wait until the plants are at least six inches in diameter. Keep the sensor gun at least 3 feet above the soil. Aim "down the row" at a target 5-10 feet away, or at individual plants, until 50-75% ground cover has developed.

2. Limit samples to sunlit leaves and the sunny side of a row.

3. Take a minimum of 20 samples to insure accuracy.

4. Once ground cover exceeds 50-75 percent, a user can begin "scanning" a field from designated positions, or while walking through the field. Aim at a target 20-30 feet away. (Figure 8)

There are several ways to measure a row crop, depending on the viewing angle of the Sensor Gun and the position of the sun.



(A) Across the row(s), perpendicular to row length.

(B) Across several rows, at some oblique angle.

(C) Down the length of one row.

How Many Samples Should I Take?

The Monitor can take many samples in seconds. Generally, the larger the area being sampled, the more readings are required. For example:

- For a field of 1 to 40 acres, 15 or 20 samples should be sufficient.
- A large field of up to 160 acres can require 20-40 samples.

Figure 8

4.3 Pointers for Specific Crops

The recommendations in this section refer to the major part of the growing season, when ground cover is nearly complete and prior to senescence (crop dry down). Add about 3 index units to these recommendations when irrigating prior to canopy closure or during crop senescence. All general guidelines for sampling (Section 2.7) apply.

Corn

The major challenge with corn is taking samples after the crop grows taller than the user. The Scheduler^{R} Plant Stress Monitor can be used while standing on a center-pivot tower or a ladder which has been placed in the field. Corn should be irrigated when the index exceeds 2.0. The corn index will normally cycle between -2 and +2. Always make sure you sample the top side of the canopy.

Soybeans

Soybean leaves follow the sun. To avoid confusion, keep the sun at your back. Irrigate when the index exceeds 2.0.

Sorghum

Prior to heading, grain sorghum is measured like any other row crop. After heading, it is necessary to avoid the heads. This is done by aiming at the leaves between rows. Irrigate when the index is exceeds 2.0.

Wheat

Most of the studies conducted on wheat have not been started until about 50-60 days after planting. For winter wheat, this corresponds to the period after spring growth begins. The Scheduler can be used on wheat as soon as the canopy appears solid green. Irrigate when the index exceeds 2.0.

Cotton (California/Arizona)

The highest cotton yields occur when the average index remains less than 1.0 between mid-June and mid-August and the maximum index remains less than 3.0 during the same period. Early in the season, index value may be as high as 6.0 before irrigation is needed. As the crop dries in late August, it should achieve an index of about 6.0 by the first of September.

Seed Alfalfa

Seed alfalfa appears to increase its productivity by cycling between low index values and high index values between irrigations. Oregon State University was able to produce 835 lbs. of seed per acre by allowing the index to reach about 8.0 before irrigating. Irrigation should reduce the index to between 0 and 1.

Tomatoes

Research indicates that tomatoes should be managed to keep the index below 2.0.

Melons (Cantaloupe, Watermelons)

Keep the index on these crops generally below 1.0. In NO case after cover develops, allow the index to exceed 3.0.

Viticulture

Research has shown the Scheduler is an effective stress management tool on grapes. The Scheduler can be used for scheduling irrigation, assessing vine vigor, and controlling bunch rot. Berry size and cluster tightness can be manipulated by stressing the vine at precise times and in precise amounts.

In the central valley of California, grape vines begin leafing out in earch March. By early May, when irrigation is required, sufficient leaf area has generally developed to use the Scheduler. General use guideleines are:

1. Stand with the sun behind your back.
2. Aim the sensor gun at the sunlit foliage of a vine 6-8 feet away.
3. Take 10-20 samples per average.
4. Once leaves become old and start drying, the index readings should not be used.
5. Varieties with small, dark leaves may be 1-3 stress units warmer than varieties with large leaves.

Because of the intense need by viticulturists to control quality and yield, the Scheduler has proven to be an especially valuable management tool. Due to the personalized expertise of this industry, we would be foolish to offer specific stress index instructions as general rules. Experience has proven that the individual viticulturalist is the best source of judgment and will quickly relate seasonal stress readings to critical cultural practices.

Potatoes

Research at Oregon State University demonstrates that the highest yields and qualities are obtained when index values are kept less than 1.0, with maximum values not to exceed 2.0 after a full canopy has developed. Prior to that time, index values may be as high as 5.0 without damage, but should generally be kept as low as possible.

1986 Results

Average Index	Yield (cwt/acre)	% #1
0	511.6	65.8
1	556.4	60.3
2	530.7	71.1
3	540.3	59.9
4	556.9	53.6
5	437.5	55.3
6	468.6	40.7
7	461.4	22.5
8	442.1	23.3
9	334.5	18.8

1987 Results

Average Index	Maximum Index	Yield (cwt/acre) (cwt/ac)	Percent #1	Average Soil water at 6 inches (bars)
0.25	2.1	443	62	-0.41
0.61	4.0	469	44	-0.37
1.36	5.1	537	46	-0.43
1.89	5.6	437	37	-0.84
2.01	5.5	400	18	-0.92
3.13	5.6	409	10	-1.57

The 1987 crop was affected by a hailstorm during August.

CHAPTER 5

INSTRUMENT FEATURES

5.1 General

1. Easy to use. Only eight buttons to push (ON/OFF, HELP, PRINT, DEL, ENTER, UP, CALC, DOWN). No computer experience needed.

2. Seven pre-programmed crops per unit.

3. Easily reprogrammed with new crops.

4. RS-232 compatible for downloading to external computers and printers.

5. Replaceable EPROM's for changing between software programs. (This change is made for the user only by our technicians, to avoid the possibility of damaging sensitive electronic components).

6. Built-in modem.

7. Real-time clock. Date and Time are stored with each average.

8. Battery test feature. The user can always check the current battery voltage by turning the Scheduler^{R} Plant Stress Monitor on and pushing the CALC button. The Scheduler will automatically warn a user if the voltage drops below 6.7 volts.

9. Visual display of the difference between crop and air temperatures.

10. Sunlight level feature to automatically delete any data collected at less than 65% full sunlight. The user can enable or disable this feature at will.

11. Audible tones to indicate when data is stored or when an error has occured.

12. Rapid-fire feature. Allows a user to collect data at the rate of 4 samples per second for a maximum of 55 samples per "data burst". After the samples from a rapid-fire data burst are processed, another data burst may be collected. All data from multiple "bursts" are combined to form a single average.

13. 94 second warm-up period. All Schedulers are built with a 94-second warm-up period if it has been more than 10 minutes since the unit was turned off. This provides a minimum time for the user to let the hardware adjust to the field environment.

5.2 Production Software Features

1. Fifteen-day data storage for stress index means for each of 30 separate fields or locations.

2. Graphic display of the stress index trends for the most recent 15 days for each of 30 fields. This allows rapid in-field decisions without using an external computer.

3. One-day storage of mean values of crop, temperature, air temperature, relative humidity, solar radiation and the stress index. Also stores the time, date, field number, crop name and number of samples associated with each average. Means (except index values) are automatically deleted at midnight.

4. User determines in advance whether the temperatures will be displayed in Centigrade or Fahrenheit.

5.3 R & D Software Features

1. One-day data storage for average values of crop temperature, air temperature, relative humidity, solar radiation, vapor pressure deficit and the stress index for 240 separate fields. Standard deviation of crop temperature, date, time, field number, crop name, and number of samples collected with each average are also stored. No data is deleted automatically.

2. Ability to transmit all data in real-time to an external RS-232 device, making it possible to capture all the data observed by the Scheduler.

3. Ability to switch between degrees Centigrade and Fahrenheit.

CHAPTER 6

INFRARED THERMOMETER CARE AND USE

6.1 How an Infrared Thermometer Works

Many Scheduler^{R} Plant Stress Monitor owners have seen infrared thermometers before, but most probably do not know how or why they work. IRT's work because every object in the universe has heat. Heat radiates from every object much in the same way light radiates from the sun or from a fire. In fact, if our eyes were sensitive to heat energy, the world would never appear dark to us.

The detector in an infrared thermometer is similar to a photo-cell. Instead of being sensitive to light, it is sensitive to heat. These type of detectors require special construction, filters and calibration in order to work properly.

6.2 Keep the IRT Clean

The IRT in the Scheduler uses advanced technology and calibration techniques. However, the accuracy of any infrared thermometer depends on keeping the lens clean. Dust (or any other foreign substance) on the lens absorbs heat. Do not allow the lens to become dirty. If it does become dirty, clean it to maintain accuracy. We recommend keeping the Scheduler in its bag (with the bag zipped) when not in use. The bag serves as a good dust protector for all the sensors in the Scheduler. No sensor works at maximum efficiency when it is dirty, but an infrared thermometer is especially sensitive to dirt. Keep it clean.

6.3 Aiming Techniques

The stress index is dependent on the quality of data sampled by the user. The following suggestions will help insure that the stress index produced by your Scheduler is valid.

1. Aim the gun at sunlit foliage only. It is essential that the Scheduler gun be aimed primarily at sunlit leaves, regardless of canopy structure. The index does not work on shaded leaves.

2. Aim at individual leaves, if necessary.

3. Keep the gun at least 3 feet above the soil surface. Air temperatures near the soil are generally higher than those just a few feet away, and it can bias your readings.

4. Aim "down" the row, if possible, at a spot about 10-15 feet away. On some tree crops, such as almonds, it is possible to stand in line with two trees, so that the Scheduler sees the other tree as background, instead of sky.

5. Try aiming "across" rows. Even when large amounts of soil are exposed, this aiming direction often produces the appearance of a solid canopy. Aim at a point 20-25 feet from where you are standing to avoid picking up soil from the rows closest to where you are standing.

6. Artificially create a sampling surface, if necessary. On some crops, such as pecans, the canopy is open, exposing large amounts of wood, sky and shadows. The only place where a solid mat of sunlit vegetation can be seen is across the tops of the trees. Since these trees may be 20-30 feet tall, it is not practical to sample pecan canopies. From ground level, the only technique identified to date is to artificially create a sample surface. This is done by visually inspecting a tree for a branch near ground level which has most of its leaves sunlit. By pulling the leaves, as if you're trying to strip them from the branch, they will cluster in front of your hand. With a few minutes of practice, it is possible to consistently create a mat of sunlit leaves with one hand, while aiming the Scheduler with the other.

7. Watch the bar-graph on the back of the gun. An unusually hot reading may be severe stress, but it may also be a hot patch of soil.

8. Sample several areas of the field.

9. Avoid taking samples from roadways. It is essential to move at least 50-100 feet into the field to make sure the air being sampled is representative of the majority of the field.

10. Sample between 11 AM and 4 PM.

11. Sunlight should be stable. Wait for 60 seconds after a cloud moves away from the sun to resume sampling. Enable the sun low feature to insure the sun is bright enough.

6.4 What an Infrared Thermometer Sees

An infrared thermometer "sees" an oval shaped area (Figure 8), similar in shape to the area lighted by a flashlight. The size of this area is controlled by how high you hold the infrared thermometer above the target area and by how far away the target is from the user.

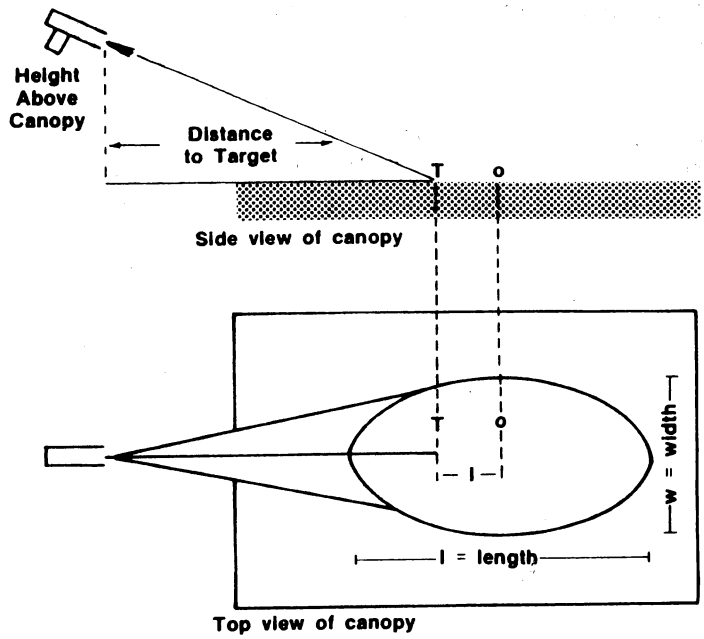


Figure 9

Dimensions of the Zone "Seen"
by the Scheduler Infrared Thermometer

Height Above Canopy (ft.)	Distance to Target (ft.)	Zone Length (ft.)	Zone Width (ft.)	Zone Area ($ft.^2$)
3	1	0.5	0.4	.2
3	5	1.6	0.8	1
3	10	5.4	1.4	6
3	20	24.4	2.8	54
3	30	83.0	4.2	274
5	5	1.4	1.0	1
5	10	3.6	1.6	4
5	20	12.9	2.9	29
5	30	31.4	4.3	105
5	40	66.2	5.6	293
5	50	138.0	7.0	762
10	5	1.8	1.6	2
10	10	2.8	2.0	4
10	20	7.1	3.1	17
10	40	25.8	5.8	117
10	60	62.8	8.6	420
10	80	132.0	11.3	1,117
10	100	276.0	14.1	3,051

6.5 Recommended Viewing Distances

The above table needs to be studied and understood to get the most accurate readings. If a user aims the Scheduler at a target further away than the maximum recommended viewing distance, the index values may be influenced by the horizon which can come into view of the infrared thermemeter.

Height of Sensor Above Canopy	Maximum Recommended Target Distance
3	30
5	50
10	110

CHAPTER 7

HARDWARE FEATURES AND SPECIFICATIONS

7.1 The 94-Second Delay

The reason a 94-second delay was built into the software is to help insure you get accurate information. Air temperature sensors accurately read the temperature of whatever air surrounds them. But if the Scheduler^{R} Plant Stress Monitor has become very hot (or cold) relative to field temperature, then the temperature of the sensor case will affect the temperature of the air drawn past the temperature sensor. Keep the case as close to air temperature as possible. The Scheduler is designed to be accurate as long as the case is within 15 degrees Fahrenheit of the surrounding air temperature.

7.2 Hardware Features

1. Aspirated Air Temperature and Humidity Sensors.

2. Infrared Thermometer

Distance:	1 inch to infinity
Range:	+ 60^{o}C from ambient
Field of view:	8^{o}
Spectral response:	8-14 um
Accuracy:	+ 0.5^{o}C
Repeatability:	+ 0.1^{o}C
Emissivity:	0.99
Operating distance:	1 inch to infinity

3. Ambient Temperature

Range:	0^{o}C to 60^{o}C
Accuracy:	+ 0.5^{o}C
Resolution:	0.1^{o}C

4. Humidity

Range:	0 to 100%
Accuracy:	+ 5%

5. Solar Radiation

Range: 0 to 100 mW/cm2
Accuracy: + 10%

6. Response Time

Screen update < 2.0 seconds
Sample frequency < 0.5 seconds

7. Microprocessor: 64-K -- 8 bit.

8. Display: 2-1/2" x 1-1/2" LCD on processor
1-1/2" x 1" on sensor gun

9. Serial Interface

RS-232 25 pin male connection
Band Rates: 50-2400 (selectable)
Character Sizes: 5-8 (selectable)
Other download parameters also selectable

10. Softside carrying case

11. Warranty: 1 year

12. Power

6 C cell batteries, with an expected life of 20 operating hours.

13. Recharging port provided for use with rechargeable batteries.

CHAPTER 8

TRANSFERRING DATA TO A COMPUTER

8.1 Communicating With Assorted Computers

One of the challenges of using computers is the fact that there are so many different types of systems. One of the popular phrases used in advertising these many computers is "IBM compatible". What does that phrase really mean? It means that the computer will run most, but sometimes not all, the software that an IBM will run. To make matters worse, there are differences among IBM machines that make it impossible to run the same software on all machines.

So, how does this impact the owner of a Scheduler^{R} Plant Stress Monitor who wants to download his field sample information to a computer? It means that he may have a very easy time transferring his data, or it means that he may have to learn more about his particular computer than he originally anticipated. With a little effort, the data can be downloaded. Don't be discouraged. If you can't get your computer to accept Scheduler data, the odds are there is a computer expert somewhere in your area that can make it happen. You can always phone us for advice. Our toll-free number is (800) 356-0458.

8.2 Before You Get Started

Check your system to be sure you have a serial communications card in your computer. This is the card which allows you to communicate through a modem to other computers. In the event you do not have a communications card, you should consult your computer supplier for the card that is right for your system.

The Scheduler cable has a 25-pin connector. In some cases, the communication cards have other-size connectors. If this is the case, your computer supplier will need to make an adapter to fit the 25-pin Scheduler cable. The following information will be important to your computer supplier.

The pin connections for the Scheduler cable are:

25-Pin Connector	Function
1	Case ground
2	Receive signal
3	Transmit signal
7	Signal ground
8	DTR out
20	DSR in

8.3 Standard Downloading Commands

Step 1: Configure your Scheduler using the Print Option with the following set-up: (see operators manual for complete instructions)

Baud 1200
Char Size 8
Stop Bits 2
Parity None
Xon/Xoff Disabled
Sun Low Disabled

Step 2: Connect the Scheduler to the computer serial port.

Step 3: Make sure the DOS file "Mode.com" is available on the drive you are using (it should be on your hard disk if using the C drive, or on your floppy disk if using the A drive). Type "DIR MODE.COM" to see if it is available.

Step 4: Using the keyboard on your computer, issue the following commands:

(a) Mode COM1:12,N,8,2
(b) Copy COM1 *.*
(*.* is the name you give the file.)

Note: Your communications card may be on COM2. If so, use COM2 above.

Step 5: Step through the PRINT option on the Scheduler.

Step 6: All data should be transferred to the file. You will not see any data on the screen.

Step 7: You will know the Scheduler has sent its data when you get the message "Erase Data?"

Step 8: On your computer, issue the following command Type *.* to verify that the data is in the file.

CHAPTER 9

UNIVERSITY/RESEARCH SUPPORT

The baselines used in the Scheduler^{R} Plant Stress Monitor are the result of experiments conducted in many locations by many people. Many of these experiments will be published in professional journals and university reports. Among the Universities which have helped develop the baselines in the Scheduler are California State University (Fresno), University of California, Washington State University, Oregon State University and University of Nebraska. USDA researchers in many locations have also assisted. Scheduler owners have also helped develop baselines.

NOTES:

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SCHEDULER[R] PLANT STRESS MONITOR

TECHNICAL/TRAINING MANUAL

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SCHEDULER^{R} PLANT STRESS MONITOR

TRAINING AND TECHNICAL MANUAL

CHAPTER 1

INTRODUCTION

1.1 Purpose of the Scheduler^{R} Plant Stress Monitor

Plants, like humans react to their environment. Plant temperature is the key indicator of how a plant is reacting. The Scheduler^{R} Plant Stress Monitor contains an index based on plant temperature which allows you to make an accurate determination of stress status and make management decisions based on plant condition. The plant stress index allows you to detect stress before visual symptoms develop. The result is a new technology that allows the grower to produce healthier crops, and often obtain a savings in water, fuel and labor.

1.2 Theoretical Summary

Plant leaves contain small openings similar to the pores on human skin. When these pores, called stomates, are open, leaves evaporate water at a rate which is controlled by the properties of the surrounding air and the intensity of the impinging sunlight. Several factors cause stomates to close: water stress, disease and insect damage are three significant factors. When the stomates start to close, if the sunlight is sufficiently intense, a leave will evaporate water at a lower rate than a leaf with open stomates. The tighter the stomates close, the slower the evaporation rate from the leaf. The result is that a leaf with closed stomates will be hotter than a leaf with open stomates. This hotter leaf temperature can then be detected with infrared technology and, when combined with a specific crop model, can be converted to a stress index.

1.3 Historical Summary

The first evidence that water-stressed plants are warmer than well-watered plants was reported in 1843, with

the aid of mercury thermometers. The second report on this phenomenon was made in 1875. Although the phenomenon was well documented, it was evident that mercury thermometers were simply not a practical tool. Beyond that, theory to explain the phenomenon could not be identified. By 1923, the USDA had begun to use crude thermocouples to study the effect of water stress on plant temperatures. These studies revealed important correlations for a large number of plant types. These studies were interruped by World War II. The scientists of that era developed several conflicting theoretical explanations.

In the early 1950's, the USDA and several universities again began studying the phenomenon. By this time, it had been realized that crop yields and quality are affected by mild water stress and that temperature stress was important to monitor. A comprehensive theory, which was based on heat transfer and aerodynamic principles, was proposed. Portable instrumentation did not exist to test this theory. In the 1960's, the military declassified a relatively crude infrared thermometer. Some university researchers began using the tool in the field to study crops, but the high cost and technical operating difficulties limited its use.

In the mid 1970's, a relatively inexpensive and reliable infrared thermometer became available. Several university and USDA agencies began researching the application of this tool for agricultural crops, both in stress detection and yield monitoring. By 1980, a few researchers had effectively demonstrated the application of these theories to scheduling irrigations in corn and monitoring yield losses in wheat, corn, alfalfa and sorghum. Between 1980 and 1984, theories were developed which finally allowed a stress researcher in one part of the country to compare his work with that taking place in another area. The theoretical basis for irrigation using infrared thermometers was established and several scientists were urging its use.

In 1984, Standard Oil of Ohio became involved in the advancement of this technology and funded tests to validate the theories. Although the market aspects were not fully understood, it was believed to be a powerful new tool for the agricultural industry. In 1985, large scale tests of the technology were conducted by Standard Oil, which clearly demonstrated the effectiveness of the technology. In addition, these tests also identified several opportunities for growers to benefit from the use of this technology. During 1986 and 1987, the technology was validated on over two dozen major agricultural crops, including cotton, grapes, melons and turf.

It is important to note that in all these crops, irrigation scheduling is only one application of this technology. In addition, infrared technology can be used to assess the uniformity of an irrigation system, thereby offering an irrigator a tool with which to "fine tune" his system. Controlling stress levels and disease detection are other important applications.

CHAPTER 2

THE STRESS INDEX AND FIELD USE

2.1 Leaves

When people get sick, their temperature rises above 98.6°F. The higher the temperature, the more serious the sickness. When plants are thirsty, or sick, their transpiration rate is lower than it should be. The result is a plant that is hotter than it should be. By measuring leaf temperatures and the environment, direct feedback from the plants can be translated into a form which is useful for management purposes. (Figures 1 and 2)

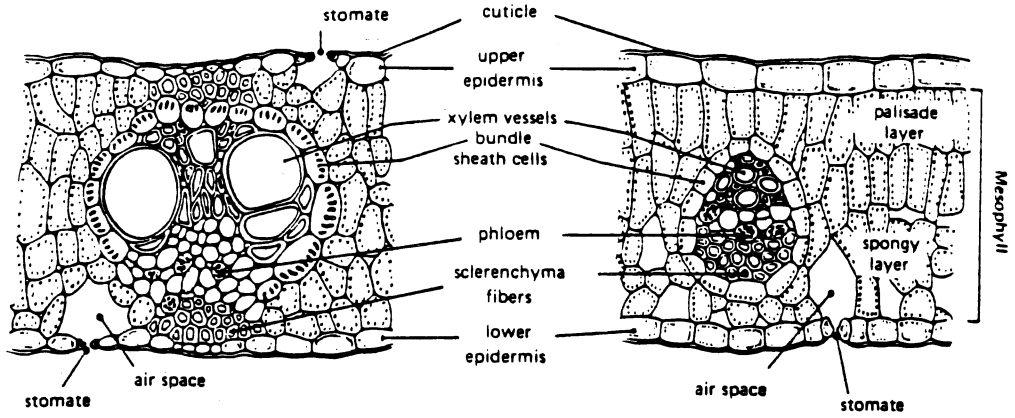


Diagram of the cross section of a monocot and a dicot leaf. [From R. H. Arnett, Jr., and D. C. Braungart: *An Introduction to Plant Biology,* 3rd ed. The C. V. Mosby Co., St. Louis, 1970.

Figure 1

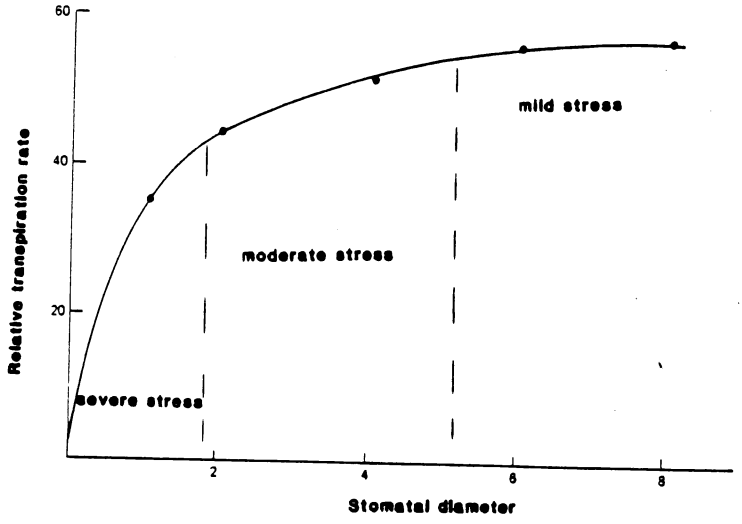


Figure 2

2.2 Stomata

Small pores on the surface of leaves (stomata) give a leaf the ability to regulate the rate at which carbon dioxide and water vapor move into, and out of, the leaf. Stomata are generally open in the day and closed at night. Stress (water, disease, insect) will cause stomata to close during the day. When the sun is shining brightly, a leaf with closed stomata will be hotter than a leaf with open stomata. (Figure 3)

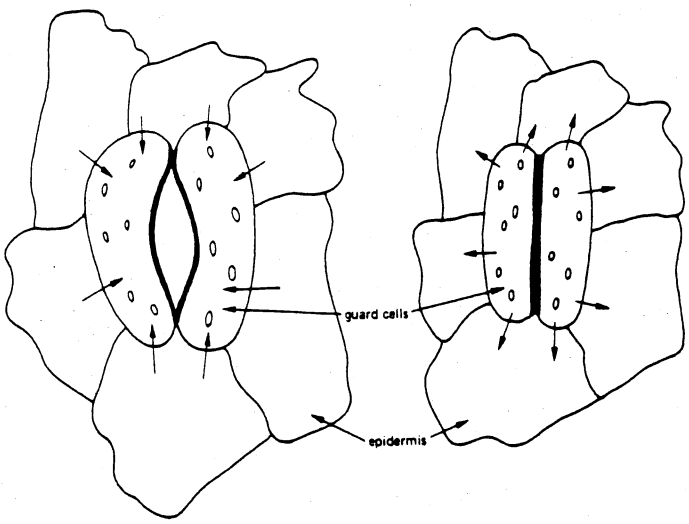


Diagram of a stomate. Arrows show direction of water movement.

Figure 3

2.3 Stress Index

In 1982, the USDA proposed a plant stress index known as the Crop Water Stress Index (CWSI) (Jackson, 1982). This index was based on an extensive review of the science relating to leaf temperatures, and on field research conducted by the USDA since the 1920s.

The results of these USDA studies show that there is a strong correlation between the evironmental parameters of air temperature, relative humidity, and sunlight with leaf temperatures for each plant species.

Although it has been possible to measure the separate components of CWSI since the mid 1970s, no instrument existed which could automatically measure all the parameters and provide answers in the field until the Scheduler^{R} Plant Stress Monitor was developed in 1984.

Since 1984, Standard Oil researchers have learned a great deal about the practicalities of using CWSI. Standard Oil has become the leader in understanding the theory and practical usage of this powerful index. Proprietary adjustments to the theory have been included in the Scheduler which allow the index to perform well in all agricultural areas.

2.4 The Drying Power of the Air

At a given temperature, moisture saturated air holds a known weight of water. In the field, the air is generally not saturated. The difference between the weight of water air can hold and the amount of water it does hold is known as the vapor pressure deficit. As the vapor pressure deficit increases, the drying power of the air increases. The drying power of the air is the ability of air to evaporate water (from a leaf or any other surface). The stronger the drying power of the air, the greater the transpiration of water from a leaf surface. This, in turn, lowers the leaf temperature because of the cooling effect of transpiration. The drying power of the air not only controls leaf temperature, but also controls the rate at which diseases develop.

2.5 Factors Which Affect Index Values

The Scheduler measures the four parameters of Air Temperature, Relative Humidity, Solar Radiation and Crop Canopy Temperature from which it calculates a plant stress index (PSI). This crop-specific index (or crop model) is a statistical representation of how a specific crop type will react to the heat load placed on it from its growing environment in both stressed and non-stressed conditions.

The index theoretically ranges between 0 and 10. In the field, it is common to see values ranging from -2 to 10. The following factors have differing effects on the plant stress index:

1. Clouds have a major effect on index values. When a cloud moves in front of the sun, the index decreases rapidly. To avoid confusion, we recommend using the index only when the sun is shining brightly on the target area. Under cloudy conditions, the index on well-irrigated areas may go as low as -10. (Figure 4)

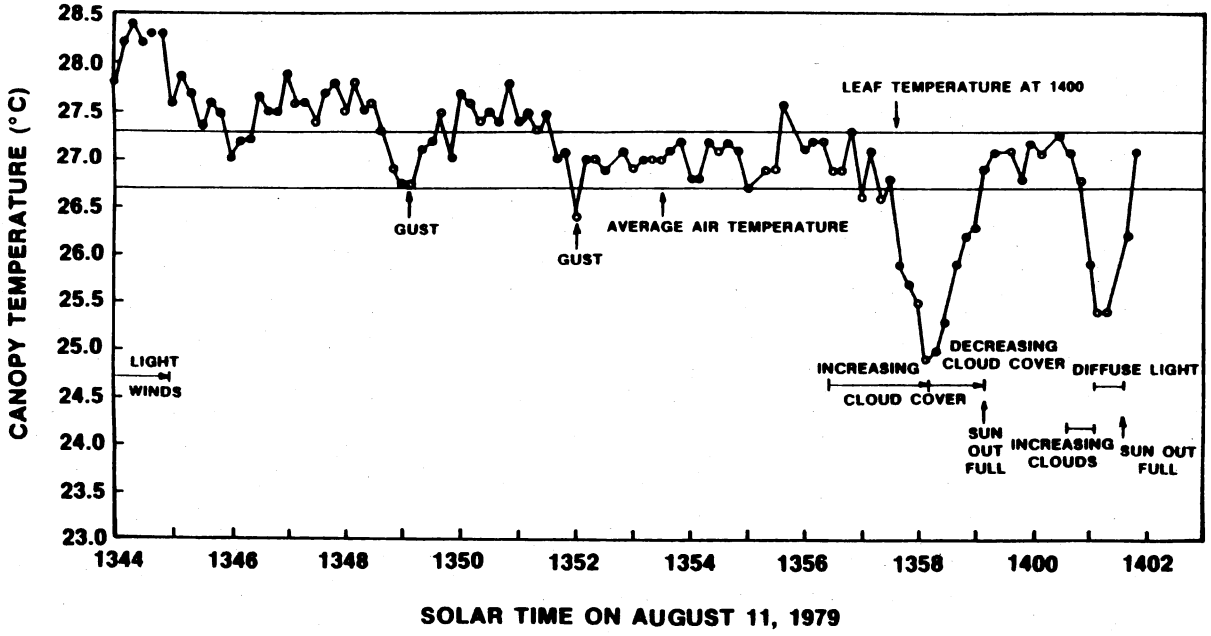


Figure 4

2. Windspeed. Wind has a minor effect on the index. (Figure 5)

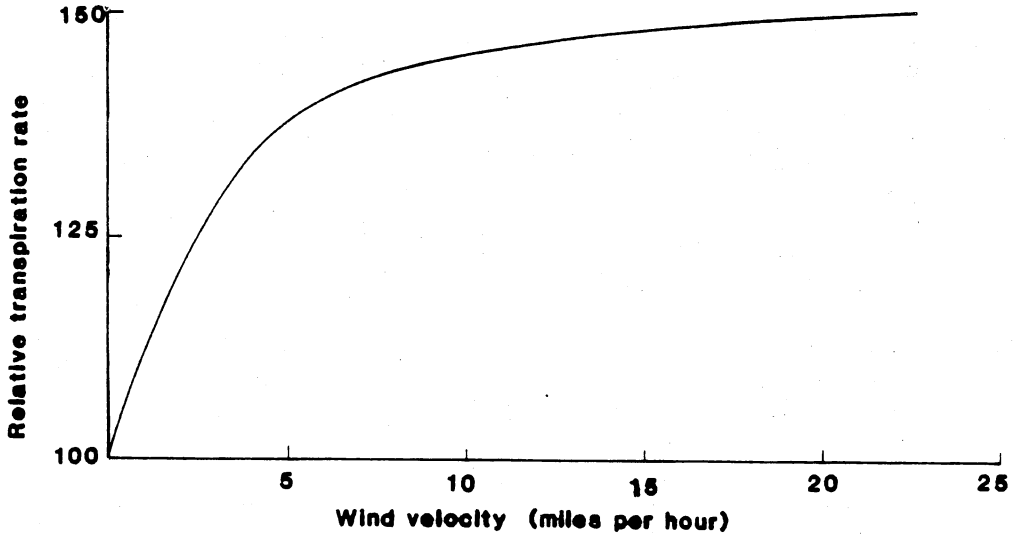
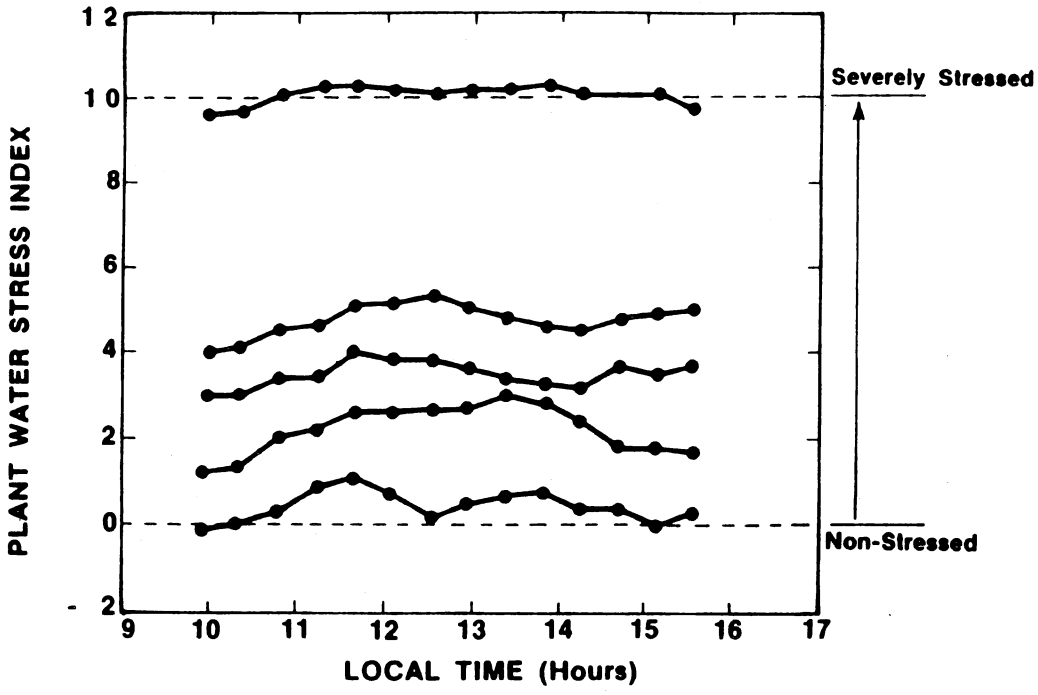


Figure 5

3. Time of day. The index changes only slightly between 11 AM and 4 PM but undergoes major changes outside of these limits. (Figure 6)



Plant water stress index as a function of time for five differently stressed plots of alfalfa at Phoenix, Arizona on Speptember 17, 1980.

Figure 6

4. Air temperature. The index for a crop is defined for normal growing conditions. When the air temperature becomes much cooler than normal, the index will decrease, reducing the effectiveness of the index.

2.6 Interpreting the Plant Stress Index

Each unit increase in the Plant Stress Index corresponds to approximately a 10% decrease in the transpiration rate. For example, if one area has an index of 1.2 and a second area has an index of 3.2, then the second area is transpiring water about 20% slower than the first area.

General Index Interpretations

< 0	No stress: (usually optimum yields)
0-2	Minimal stress: (usually no effect on yields or quality)
2-5	Moderate stress: (sustained readings in this range reduce yields and quality)
5-8	High stress: (sustained readings cause visual symptoms)
8-10	Extreme stress: (plant is in extremely poor conditon)

General Index Patterns

The index usually cycles between no stress and moderate stess values between irrigations. It is common to see an increase of 1-2 stress units after an irrigation. This pattern is caused by lack of oxygen, especially in heavy soils caused by saturation of the soil profile. As drainage occurs, there is a rapid decrease in the index. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall. Overcast skies, clouds, or cool weather cause a temporary decrease in index values.

In row crops, it is typical for index values to be moderate early in the season. As the roots grow deeper and leaf area increases, the index value becomes progressively lower. During the major portion of the season, the index should cycle from no stress to moderate stress index values between irrigations. Late in the season, as the leaves dry, the index will gradually increase to moderate levels.

Yield/Quality Relationships

In general, the cooler a crop stays, the higher the yields and the better the quality. In applications where stress is desired, the use of the index insures the stress levels remain under control.

2.7 Using the Scheduler in the Field

Several factors can affect the index. Experience, consistency of use, proper aiming technique and effective data analysis are the keys to getting good results.

For best results, remember the following guidelines:

1. Stage of growth. Young plants, especially in row crops, have higher index values than large plants. This is normal. For example, a young cotton plant may have minimum index values of 2.0, but a mature cotton plant has minimum index values less than 0.

2. Target area. Imagine for a moment that the sensor gun is a flashlight. The area illuminated by this flashlight depends on where you aim it. This is also true of the sensor gun. Although you aim the Scheduler like a gun, the area measured is seen like a flashlight. Remember, if your eye can see soil, so can the Scheduler. It must see crop canopy to be accurate.

3. The best readings are made when the sunlight is bright and stable on the crop.

4. Take samples between 11 AM and 4 PM in the summer growing season, and between 1 PM and 3 PM in the winter growing season.

5. Take at least 30 samples in the field. Try to include readings from at least 3 separate areas.

6. If you leave the Scheduler in a hot truck , or a cold office, it will take a little time to adjust to the field environment. The Scheduler works best when the hardware temperature is reasonably close to ambient conditions in the field.

7. Keep the sensor gun at least 3 feet above the soil. Sampling the air temperature near the soil will invalidate the index.

8. Plants must be dry and free from dew.

9. The user must be in the field. You cannot take readings from pick-up windows since air temperatures around vehicles, roads or access lanes are often different than in the field.

10. Always keep the sun at your back.

2.8 Simple Operating Instructions

Turn the Scheduler on properly.

1. Step out of the truck.
2. Remove the Scheduler from its case.
3. Remove the sensor gun from its holster.
4. Turn the Scheduler on, keeping the gun out of its holster.
5. During the 94 second count-down, walk to your target area.
6. Before taking your first sample, watch the air temperature reading. It should be stable (not increasing or decreasing).
7. If the sensor gun case feels very hot (or very cool), let it adjust for a few more minutes before taking your first sample. Remember, the Scheduler works fast anyway. Waiting a minute or two for it to adjust to the field environment will insure accuracy and is well worth the wait.

For a complete explanation, refer to the owners' operating manual.

CHAPTER 3

COMPARING THE SCHEDULER^{R} PLANT STRESS MONITOR TO OTHER METHODS

3.1 Pressure Bomb Comparison to the Scheduler^{R} Plant Stress Monitor

The general relationship between pressure bomb readings and Scheduler^{R} Plant Stress Monitor stress index readings is linear (Figure 7) according to research conducted by the University of California. This research also shows that users should not try to develop their own correlations between Scheduler and pressure bomb readings. Two reasons for this include differences in the scale of measurement (single leaf vs. whole canopy) and sampling differences (minutes for pressure vs. seconds for the Scheduler).

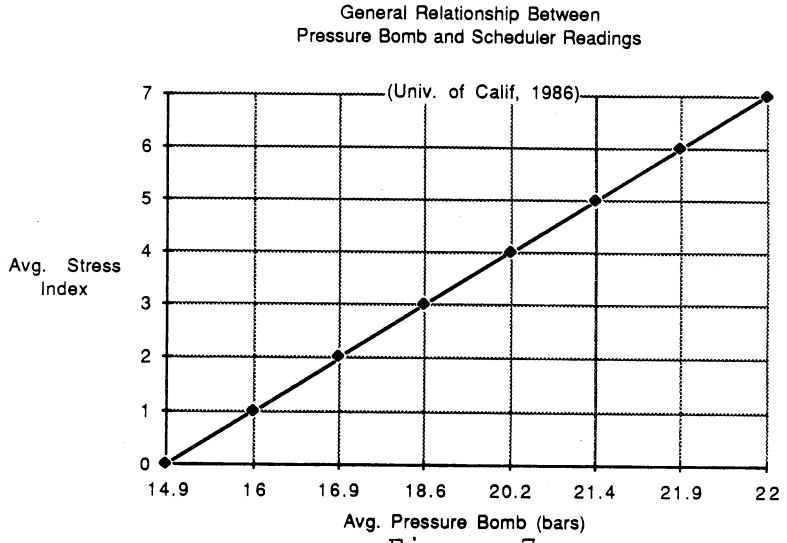


Figure 7

3.2 Soil Moisture

In general, there is a very high correlation between soil moisture deficits and index readings. As index readings increase, soil moisture deficits become larger. Use of the Scheduler with good soil moisture programs will give the grower a better picture of both soil depletion and its effect on the growing plant, providing superior inputs to irrigation scheduling.

3.3 Statistical Benefits

Growers need to realize that all management techniques such as sampling soil moisture, sampling leaf water potential with pressure bombs or sampling stress index values are statistical processes. In a sense, modern farm management essentially treats a farm as a commercial-scale experiment. Attempts are made at repeating the treatments and therefore, achieving top economic results year after year. Statistics play a vital role in effective farm management, whether they are used knowingly or not by the grower.

The Scheduler can collect and process 17 samples in less than one minute and 86 samples in five minutes. Each sample will incorporate the behavior of hundreds of plants. The Scheduler is the only plant stress analysis tool capable of providing a grower with the volume of sampling required for statistical accuracy.

CHAPTER 4

GUIDELINES FOR SPECIFIC CROPS

4.1 Index Values

There are two ways of summarizing index information. One way is to use the season-long average. This number is important, but can sometimes be misleading. For example, an average index of 1.0 can be achieved by irrigating a crop so that its index varies only slightly on either side of 1.0. A crop can also be irrigated so that the index cycles between -2 and +3 between irrigations. In both cases, the average index is the same.

The season average index values for most plants are typically 2 or less, but crops differ significantly in the range of the index values between irrigations. The range of index values which is best is dependent on the crop and on the stage of growth.

4.2 Young Plants

The normal expected stress index for young plants is higher than more mature plants. For example, a stress index of 4 or 5 at 40% ground cover would be normal for young plants, but would indicate stress at 100% ground cover.

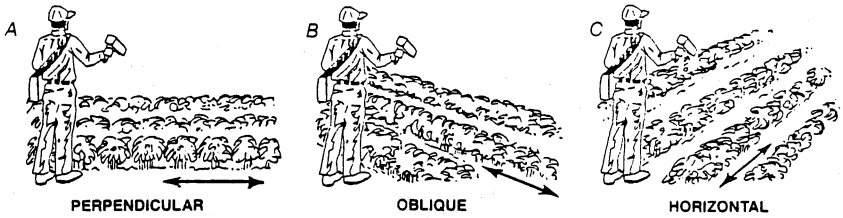
1. Wait until the plants are at least six inches in diameter. Keep the sensor gun at least 3 feet above the soil. Aim "down the row" at a target 5-10 feet away, or at individual plants, until 50-75% ground cover has developed.

2. Limit samples to sunlit leaves and the sunny side of a row.

3. Take a minimum of 20 samples to insure accuracy.

4. Once ground cover exceeds 50-75 percent, a user can begin "scanning" a field from designated positions, or while walking through the field. Aim at a target 20-30 feet away. (Figure 8)

There are several ways to measure a row crop, depending on the viewing angle of the Sensor Gun and the position of the sun.



(A) Across the row(s), perpendicular to row length.

(B) Across several rows, at some oblique angle.

(C) Down the length of one row.

How Many Samples Should I Take?

The Monitor can take many samples in seconds. Generally, the larger the area being sampled, the more readings are required. For example:

- For a field of 1 to 40 acres, 15 or 20 samples should be sufficient.
- A large field of up to 160 acres can require 20-40 samples.

Figure 8

4.3 Pointers for Specific Crops

The recommendations in this section refer to the major part of the growing season, when ground cover is nearly complete and prior to senescence (crop dry down). Add about 3 index units to these recommendations when irrigating prior to canopy closure or during crop senescence. All general guidelines for sampling (Section 2.7) apply.

Corn

The major challenge with corn is taking samples after the crop grows taller than the user. The Scheduler^{R} Plant Stress Monitor can be used while standing on a center-pivot tower or a ladder which has been placed in the field. Corn should be irrigated when the index exceeds 2.0. The corn index will normally cycle between -2 and +2. Always make sure you sample the top side of the canopy.

Soybeans

Soybean leaves follow the sun. To avoid confusion, keep the sun at your back. Irrigate when the index exceeds 2.0.

Sorghum

Prior to heading, grain sorghum is measured like any other row crop. After heading, it is necessary to avoid the heads. This is done by aiming at the leaves between rows. Irrigate when the index is exceeds 2.0.

Wheat

Most of the studies conducted on wheat have not been started until about 50-60 days after planting. For winter wheat, this corresponds to the period after spring growth begins. The Scheduler can be used on wheat as soon as the canopy appears solid green. Irrigate when the index exceeds 2.0.

Cotton (California/Arizona)

The highest cotton yields occur when the average index remains less than 1.0 between mid-June and mid-August and the maximum index remains less than 3.0 during the same period. Early in the season, index value may be as high as 6.0 before irrigation is needed. As the crop dries in late August, it should achieve an index of about 6.0 by the first of September.

Seed Alfalfa

Seed alfalfa appears to increase its productivity by cycling between low index values and high index values between irrigations. Oregon State University was able to produce 835 lbs. of seed per acre by allowing the index to reach about 8.0 before irrigating. Irrigation should reduce the index to between 0 and 1.

Tomatoes

Research indicates that tomatoes should be managed to keep the index below 2.0.

Melons (Cantaloupe, Watermelons)

Keep the index on these crops generally below 1.0. In NO case after cover develops, allow the index to exceed 3.0.

Viticulture

Research has shown the Scheduler is an effective stress management tool on grapes. The Scheduler can be used for scheduling irrigation, assessing vine vigor, and controlling bunch rot. Berry size and cluster tightness can be manipulated by stressing the vine at precise times and in precise amounts.

In the central valley of California, grape vines begin leafing out in earch March. By early May, when irrigation is required, sufficient leaf area has generally developed to use the Scheduler. General use guideleines are:

1. Stand with the sun behind your back.
2. Aim the sensor gun at the sunlit foliage of a vine 6-8 feet away.
3. Take 10-20 samples per average.
4. Once leaves become old and start drying, the index readings should not be used.
5. Varieties with small, dark leaves may be 1-3 stress units warmer than varieties with large leaves.

Because of the intense need by viticulturists to control quality and yield, the Scheduler has proven to be an especially valuable management tool. Due to the personalized expertise of this industry, we would be foolish to offer specific stress index instructions as general rules. Experience has proven that the individual viticulturalist is the best source of judgment and will quickly relate seasonal stress readings to critical cultural practices.

Potatoes

Research at Oregon State University demonstrates that the highest yields and qualities are obtained when index values are kept less than 1.0, with maximum values not to exceed 2.0 after a full canopy has developed. Prior to that time, index values may be as high as 5.0 without damage, but should generally be kept as low as possible.

1986 Results

Average Index	Yield (cwt/acre)	% #1
0	511.6	65.8
1	556.4	60.3
2	530.7	71.1
3	540.3	59.9
4	556.9	53.6
5	437.5	55.3
6	468.6	40.7
7	461.4	22.5
8	442.1	23.3
9	334.5	18.8

1987 Results

Average Index	Maximum Index	Yield (cwt/acre) (cwt/ac)	Percent #1	Average Soil water at 6 inches (bars)
0.25	2.1	443	62	-0.41
0.61	4.0	469	44	-0.37
1.36	5.1	537	46	-0.43
1.89	5.6	437	37	-0.84
2.01	5.5	400	18	-0.92
3.13	5.6	409	10	-1.57

The 1987 crop was affected by a hailstorm during August.

CHAPTER 5

INSTRUMENT FEATURES

5.1 General

1. Easy to use. Only eight buttons to push (ON/OFF, HELP, PRINT, DEL, ENTER, UP, CALC, DOWN). No computer experience needed.

2. Seven pre-programmed crops per unit.

3. Easily reprogrammed with new crops.

4. RS-232 compatible for downloading to external computers and printers.

5. Replaceable EPROM's for changing between software programs. (This change is made for the user only by our technicians, to avoid the possibility of damaging sensitive electronic components).

6. Built-in modem.

7. Real-time clock. Date and Time are stored with each average.

8. Battery test feature. The user can always check the current battery voltage by turning the Scheduler^{R} Plant Stress Monitor on and pushing the CALC button. The Scheduler will automatically warn a user if the voltage drops below 6.7 volts.

9. Visual display of the difference between crop and air temperatures.

10. Sunlight level feature to automatically delete any data collected at less than 65% full sunlight. The user can enable or disable this feature at will.

11. Audible tones to indicate when data is stored or when an error has occured.

12. Rapid-fire feature. Allows a user to collect data at the rate of 4 samples per second for a maximum of 55 samples per "data burst". After the samples from a rapid-fire data burst are processed, another data burst may be collected. All data from multiple "bursts" are combined to form a single average.

13. 94 second warm-up period. All Schedulers are built with a 94-second warm-up period if it has been more than 10 minutes since the unit was turned off. This provides a minimum time for the user to let the hardware adjust to the field environment.

5.2 Production Software Features

1. Fifteen-day data storage for stress index means for each of 30 separate fields or locations.

2. Graphic display of the stress index trends for the most recent 15 days for each of 30 fields. This allows rapid in-field decisions without using an external computer.

3. One-day storage of mean values of crop, temperature, air temperature, relative humidity, solar radiation and the stress index. Also stores the time, date, field number, crop name and number of samples associated with each average. Means (except index values) are automatically deleted at midnight.

4. User determines in advance whether the temperatures will be displayed in Centigrade or Fahrenheit.

5.3 R & D Software Features

1. One-day data storage for average values of crop temperature, air temperature, relative humidity, solar radiation, vapor pressure deficit and the stress index for 240 separate fields. Standard deviation of crop temperature, date, time, field number, crop name, and number of samples collected with each average are also stored. No data is deleted automatically.

2. Ability to transmit all data in real-time to an external RS-232 device, making it possible to capture all the data observed by the Scheduler.

3. Ability to switch between degrees Centigrade and Fahrenheit.

CHAPTER 6

INFRARED THERMOMETER CARE AND USE

6.1 How an Infrared Thermometer Works

Many Scheduler[R] Plant Stress Monitor owners have seen infrared thermometers before, but most probably do not know how or why they work. IRT's work because every object in the universe has heat. Heat radiates from every object much in the same way light radiates from the sun or from a fire. In fact, if our eyes were sensitive to heat energy, the world would never appear dark to us.

The detector in an infrared thermometer is similar to a photo-cell. Instead of being sensitive to light, it is sensitive to heat. These type of detectors require special construction, filters and calibration in order to work properly.

6.2 Keep the IRT Clean

The IRT in the Scheduler uses advanced technology and calibration techniques. However, the accuracy of any infrared thermometer depends on keeping the lens clean. Dust (or any other foreign substance) on the lens absorbs heat. Do not allow the lens to become dirty. If it does become dirty, clean it to maintain accuracy. We recommend keeping the Scheduler in its bag (with the bag zipped) when not in use. The bag serves as a good dust protector for all the sensors in the Scheduler. No sensor works at maximum efficiency when it is dirty, but an infrared thermometer is especially sensitive to dirt. Keep it clean.

6.3 Aiming Techniques

The stress index is dependent on the quality of data sampled by the user. The following suggestions will help insure that the stress index produced by your Scheduler is valid.

1. Aim the gun at sunlit foliage only. It is essential that the Scheduler gun be aimed primarily at sunlit leaves, regardless of canopy structure. The index does not work on shaded leaves.

2. Aim at individual leaves, if necessary.

3. Keep the gun at least 3 feet above the soil surface. Air temperatures near the soil are generally higher than those just a few feet away, and it can bias your readings.

4. Aim "down" the row, if possible, at a spot about 10-15 feet away. On some tree crops, such as almonds, it is possible to stand in line with two trees, so that the Scheduler sees the other tree as background, instead of sky.

5. Try aiming "across" rows. Even when large amounts of soil are exposed, this aiming direction often produces the appearance of a solid canopy. Aim at a point 20-25 feet from where you are standing to avoid picking up soil from the rows closest to where you are standing.

6. Artificially create a sampling surface, if necessary. On some crops, such as pecans, the canopy is open, exposing large amounts of wood, sky and shadows. The only place where a solid mat of sunlit vegetation can be seen is across the tops of the trees. Since these trees may be 20-30 feet tall, it is not practical to sample pecan canopies. From ground level, the only technique identified to date is to artificially create a sample surface. This is done by visually inspecting a tree for a branch near ground level which has most of its leaves sunlit. By pulling the leaves, as if you're trying to strip them from the branch, they will cluster in front of your hand. With a few minutes of practice, it is possible to consistently create a mat of sunlit leaves with one hand, while aiming the Scheduler with the other.

7. Watch the bar-graph on the back of the gun. An unusually hot reading may be severe stress, but it may also be a hot patch of soil.

8. Sample several areas of the field.

9. Avoid taking samples from roadways. It is essential to move at least 50-100 feet into the field to make sure the air being sampled is representative of the majority of the field.

10. Sample between 11 AM and 4 PM.

11. Sunlight should be stable. Wait for 60 seconds after a cloud moves away from the sun to resume sampling. Enable the sun low feature to insure the sun is bright enough.

6.4 What an Infrared Thermometer Sees

An infrared thermometer "sees" an oval shaped area (Figure 8), similar in shape to the area lighted by a flashlight. The size of this area is controlled by how high you hold the infrared thermometer above the target area and by how far away the target is from the user.

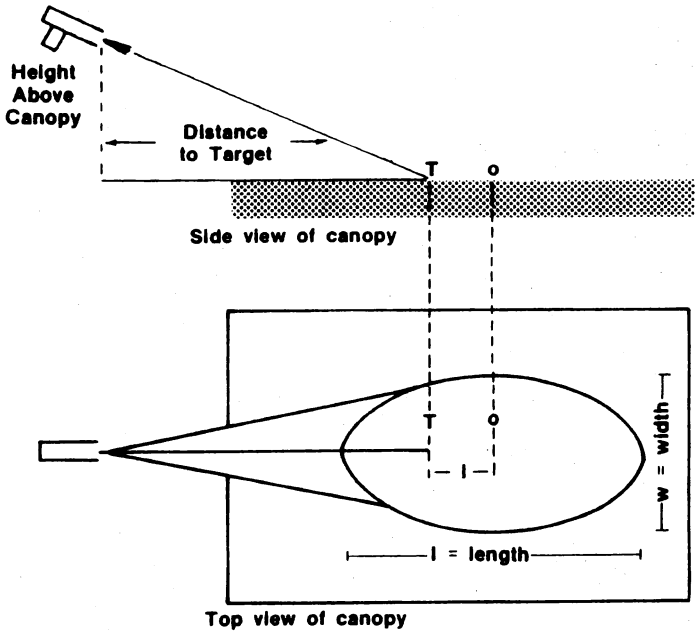


Figure 9

Dimensions of the Zone "Seen"
by the Scheduler Infrared Thermometer

Height Above Canopy (ft.)	Distance to Target (ft.)	Zone Length (ft.)	Zone Width (ft.)	Zone Area ($ft.^2$)
3	1	0.5	0.4	.2
3	5	1.6	0.8	1
3	10	5.4	1.4	6
3	20	24.4	2.8	54
3	30	83.0	4.2	274
5	5	1.4	1.0	1
5	10	3.6	1.6	4
5	20	12.9	2.9	29
5	30	31.4	4.3	105
5	40	66.2	5.6	293
5	50	138.0	7.0	762
10	5	1.8	1.6	2
10	10	2.8	2.0	4
10	20	7.1	3.1	17
10	40	25.8	5.8	117
10	60	62.8	8.6	420
10	80	132.0	11.3	1,117
10	100	276.0	14.1	3,051

6.5 Recommended Viewing Distances

The above table needs to be studied and understood to get the most accurate readings. If a user aims the Scheduler at a target further away than the maximum recommended viewing distance, the index values may be influenced by the horizon which can come into view of the infrared thermemeter.

Height of Sensor Above Canopy	Maximum Recommended Target Distance
3	30
5	50
10	110

CHAPTER 7

HARDWARE FEATURES AND SPECIFICATIONS

7.1 The 94-Second Delay

The reason a 94-second delay was built into the software is to help insure you get accurate information. Air temperature sensors accurately read the temperature of whatever air surrounds them. But if the Scheduler^{R} Plant Stress Monitor has become very hot (or cold) relative to field temperature, then the temperature of the sensor case will affect the temperature of the air drawn past the temperature sensor. Keep the case as close to air temperature as possible. The Scheduler is designed to be accurate as long as the case is within 15 degrees Fahrenheit of the surrounding air temperature.

7.2 Hardware Features

1. Aspirated Air Temperature and Humidity Sensors.

2. Infrared Thermometer

Distance:	1 inch to infinity
Range:	+ 60°C from ambient
Field of view:	8°
Spectral response:	8-14 um
Accuracy:	+ 0.5°C
Repeatability:	+ 0.1°C
Emissivity:	0.99
Operating distance:	1 inch to infinity

3. Ambient Temperature

Range:	0°C to 60°C
Accuracy:	+ 0.5°C
Resolution:	0.1°C

4. Humidity

Range:	0 to 100%
Accuracy:	+ 5%

5. Solar Radiation

Range: 0 to 100 mW/cm2
Accuracy: + 10%

6. Response Time

Screen update < 2.0 seconds
Sample frequency < 0.5 seconds

7. Microprocessor: 64-K -- 8 bit.

8. Display: 2-1/2" x 1-1/2" LCD on processor
1-1/2" x 1" on sensor gun

9. Serial Interface

RS-232 25 pin male connection
Band Rates: 50-2400 (selectable)
Character Sizes: 5-8 (selectable)
Other download parameters also selectable

10. Softside carrying case

11. Warranty: 1 year

12. Power

6 C cell batteries, with an expected life of 20 operating hours.

13. Recharging port provided for use with rechargeable batteries.

CHAPTER 8

TRANSFERRING DATA TO A COMPUTER

8.1 Communicating With Assorted Computers

One of the challenges of using computers is the fact that there are so many different types of systems. One of the popular phrases used in advertising these many computers is "IBM compatible". What does that phrase really mean? It means that the computer will run most, but sometimes not all, the software that an IBM will run. To make matters worse, there are differences among IBM machines that make it impossible to run the same software on all machines.

So, how does this impact the owner of a Scheduler^{R} Plant Stress Monitor who wants to download his field sample information to a computer? It means that he may have a very easy time transferring his data, or it means that he may have to learn more about his particular computer than he originally anticipated. With a little effort, the data can be downloaded. Don't be discouraged. If you can't get your computer to accept Scheduler data, the odds are there is a computer expert somewhere in your area that can make it happen. You can always phone us for advice. Our toll-free number is (800) 356-0458.

8.2 Before You Get Started

Check your system to be sure you have a serial communications card in your computer. This is the card which allows you to communicate through a modem to other computers. In the event you do not have a communications card, you should consult your computer supplier for the card that is right for your system.

The Scheduler cable has a 25-pin connector. In some cases, the communication cards have other-size connectors. If this is the case, your computer supplier will need to make an adapter to fit the 25-pin Scheduler cable. The following information will be important to your computer supplier.

The pin connections for the Scheduler cable are:

25-Pin Connector	Function
1	Case ground
2	Receive signal
3	Transmit signal
7	Signal ground
8	DTR out
20	DSR in

8.3 Standard Downloading Commands

Step 1: Configure your Scheduler using the Print Option with the following set-up: (see operators manual for complete instructions)

Baud 1200
Char Size 8
Stop Bits 2
Parity None
Xon/Xoff Disabled
Sun Low Disabled

Step 2: Connect the Scheduler to the computer serial port.

Step 3: Make sure the DOS file "Mode.com" is available on the drive you are using (it should be on your hard disk if using the C drive, or on your floppy disk if using the A drive). Type "DIR MODE.COM" to see if it is available.

Step 4: Using the keyboard on your computer, issue the following commands:

(a) Mode COM1:12,N,8,2
(b) Copy COM1 *.*
(*.* is the name you give the file.)

Note: Your communications card may be on COM2. If so, use COM2 above.

Step 5: Step through the PRINT option on the Scheduler.

Step 6: All data should be transferred to the file. You will not see any data on the screen.

Step 7: You will know the Scheduler has sent its data when you get the message "Erase Data?"

Step 8: On your computer, issue the following command Type *.* to verify that the data is in the file.

CHAPTER 9

UNIVERSITY/RESEARCH SUPPORT

The baselines used in the Scheduler^{R} Plant Stress Monitor are the result of experiments conducted in many locations by many people. Many of these experiments will be published in professional journals and university reports. Among the Universities which have helped develop the baselines in the Scheduler are California State University (Fresno), University of California, Washington State University, Oregon State University and University of Nebraska. USDA researchers in many locations have also assisted. Scheduler owners have also helped develop baselines.

NOTES:

NOTES:

NOTES:

7

CARBORUNDUM

The Carborundum Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio 44139

Telephone: 216 349-6881
Fax: 216 349-6397

December 19, 1988

Mr. Bronson Gardner
The Carborundum Company
P. O. Box 391316
Solon, OH 44139

Dear Bronson:

Just a note to keep you updated on the Distributor Training School to be held January 9-13 at the Center for Irrigation Technology, California State University, Fresno. PCA credit has been applied for and when we find out the exact number of hours available for credit we will let you know.

In addition,two California State University Fresno extension credit units are available for a cost of $60.00. The attendees that want credit will need to fill out a form and pay on the first day of training. Dr. Krauter will also need to have you write a short paper of some kind to serve as an evaluation. The course will be titled Plant Science 170T and is upper division (Junior/Senior level). The $60.00 cost is an estimate from the extension director but it should be fairly accurate. In a few more days we should have the exact cost pinpointed.

Attached is a map showing our training location at CIT on the corner of Barstow and Chestnut and the suggested lodging locations. Also enclosed for your convenience is another copy of the training course itinerary.

We look forward to seeing you after the holidays.

Merry Christmas,

J. Korbin Riley
Sales Distribution Manager

JKR/jmm
cc: C. Krauter
Enclosure

1989 DISTRIBUTOR TRAINING SCHOOL

January 9-13, 1989

California State University, Fresno
Center for Irrigation Technology

Day	Time	Subject/Activity	Instructor Location
Monday	12:00-1:15	Buffet Lunch	CIT
January 9	1:15-1:30	Introduction/Mission	DeSutter
	1:30-5:00	Plant Physiology	Krauter
	Evening	Open	
Tuesday	8:00-8:30	Continental Breakfast	CIT
January 10	8:30-10:00	Intro to the CWSI Theory	Gardner/Krauter
	10:15-12:00	Intro Product Components/ Running the Program	Riley
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Sampling Technique	Gardner/Riley (field location)
	3:00-3:15	Break	
	3:15-4:00	Classroom Discussion/Intro Croplink	Krauter
	4:00-5:30	Aerial Images/Farm Mapping	Verde Technologies
Wednesday	8:00-8:30	Continental Breakfast	CIT
January 11	8:30-9:30	Data Analysis	Gardner
	9:30-9:45	Break	
	9:45-11:00	Designing a Farm Program	Carl
	11:00-12:00	Comparison and Complement/ Other Methods	Krauter
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Field Sampling (Test)	
	3:00-3:15	Break	
	3:15-4:00	Review of Field Work	Krauter
	4:00-5:00	Downloading to a PC	Gardner
	Evening	Open	
Thursday	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Reviewing Previous Day's Results	Computer Lab
	9:30-9:45	Break	
	9:45-12:00	PC Lab/Software Programs	Krauter/Gardner
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Croplink/Field Applications	Maupin/CIT
	3:00-3:15	Break	
	3:15-5:00	User Panel	Carl
	7:00-9:00	Dinner/Carborundum	
Friday	8:00-8:30	Continental Breakfast	CIT
January 13	8:30-10:00	Putting It All Together I	DeSutter
	10:00-10:30	Break	
	10:30-12:00	Putting It All Together II	DeSutter

COURSE INSTRUCTORS

Dr. Charles Krauter	Professor, Irrigation Science California State University, Fresno
Steve Carl	President, CCT Corporation

The Carborundum Company, Instrument Technologies

Steven C. DeSutter	Manager
Bronson Gardner	Ph.D., Agricultural Meterologist
J. Korbin Riley	Marketing Manager
E. William Maupin	Sales Representative/Crop Link Product Specialist

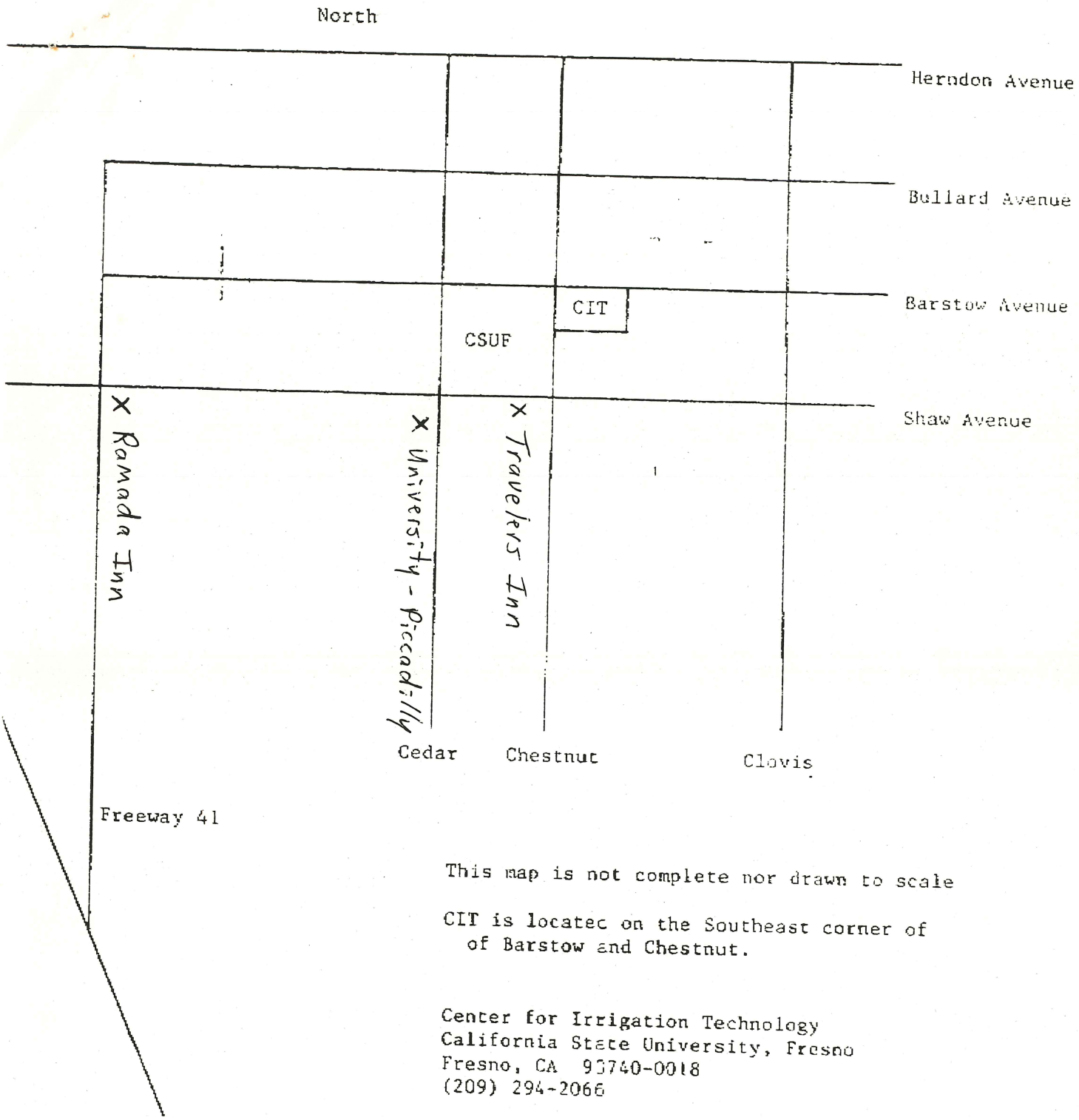
LOCAL ACCOMMODATIONS

Piccadilly (University location)
(209) 224-4200
$47 Single, $55 Double

Ramada Inn (Shaw Avenue Location)
(209) 224-4040
$49.28 Single, $55.44 Double

Travellers (Shaw Avenue location) One Block from CIT
(209) 294-0224
$29.06 Single, $33.54 Double

These are group rates through California State University and should be confirmed when reserving your room. As always, hotel rates are subject to change without notice.



This map is not complete nor drawn to scale

CIT is locatec on the Southeast corner of
of Barstow and Chestnut.

Center for Irrigation Technology
California State University, Fresno
Fresno, CA 93740-0018
(209) 294-2066

CARBORUNDUM

The Carborundum Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio 44139

Telephone: 216 349-6881
Fax: 216 349-6397

November 22, 1988

Dr. Charles Krauter
Department of Plant Science
Fresno State University
Fresno, CA 93740-0072

Dear Dr. Krauter:

I am finally getting around to summarizing our meeting of a couple of weeks ago. In the future please address any questions about the agenda to Korbin, Bronson or me as Mr. Lopez is no longer with our organization.

Following is my interpretation of the course schedule per our most recent revision. Please advise me if you see it any differently:

Deadline 31 December

1989 DISTRIBUTOR TRAINING SCHOOL
January 9-13, 1989
Center for Irrigation Technology

Day	Time	Subject/Activity	Instructor Location
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	3:00-3:15	Break	
	3:15-4:00	Classroom Discussion Intro Croplink	Krauter
	4:00-5:30	Aerial Images/Farm Mapping	Verde Technologies
	7:00-9:00	Dinner (Verde) (Steve Carl Follow-up)	

Manual

Aiming

Day	Time	Subject/Activity	Instructor Location
Wednesday January 11	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Data Analysis	Gardner
	9:30-9:45	Break	
	9:45-11:00	Designing a Farm Program	Carl
	11:00-12:00	Comparison and Compliment Other Methods	Krauter
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Field Sampling (Test)	
	3:00-3:15	Break	
	3:15-4:00	Review of Field Work	Krauter
	4:00-5:00	Downloading to a PC	Gardner
	Evening	Open	
Thursday January 12	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Reviewing Previous Day's Results	Computer Lab
	9:30-9:45	Break	
	9:45-12:00	PC Lab/Software Programs	Krauter/Gardner
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Croplink/Field Applications	Maupin/CIT
	3:00-3:15	Break	
	3:15-5:00	User Panel	Carl
	7:00-9:00	Dinner/Carborundum	
Friday January 13	8:00-8:30	Continental Breakfast	CIT
	8:30-10:00	*Putting it All Together I	DeSutter
	10:00-10:30	Break	
	10:30-12:00	*Putting it All Together II	DeSutter

P.C. / DOS / R+D Programs

* Video taped selling exercises, coaching on selling skills to implement the fundamentals taught during the week.

Please agree or offer amendments to this schedule so it can be finalized

Best regards,

Steven C. DeSutter
Manager, Sensor Technologies

SCD/lb

cc: S. Carl
B. R. Gardner
J. K. Riley
E. W. Maupin

You are

cordially invited to

1989 DISTRIBUTOR TRAINING SCHOOL

For Distributors of the

Scheduler™
Plant Stress Monitor

Monday, Noon, January 9

through

Friday, Noon, January 13

at the

Center for Irrigation Technology
California State University, Fresno

CARBORUNDUM

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Sensor Technologies
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December 9, 1988

DISTRIBUTOR TRAINING SCHOOL

Mr. Bronson Gardner
The Carborundum Company
P. O. Box 391316
Solon, OH 44139

Dear Bronson:

Even though we are tieing up our loose ends from 1988 just as you are, it's already time to start planning for next year! In order to kick the year off in a productive way, we are holding an intensive training workshop beginning at noon on Monday, January 9 through noon on Friday, January 13 at California State University, Fresno for our west coast distributing partners. This is an important opportunity for you to receive comprehensive training on the Scheduler[R] Plant Stress Monitor and the new Croplink[TM] Crop Monitoring System product lines. The course will cover plant physiology, the Crop Water Stress Index, how to design a farm use program, and key selling skills helping you put it all together.

Each day a continental breakfast and buffet lunch will be provided as well as a group dinner on Thursday evening, January 12. Transportation and lodging will be your responsibility. We have provided a list of local accommodations to assist you.

We at Carborundum feel that the workshop will be extremely beneficial for you and because we feel so strongly the first two people attending the workshop from your business will attend for **FREE**. Each additional person over the limit of two will be charged a $200.00 tuition fee. Lynn Bucknell, our Sales Correspondent, will be telephoning you in the next few days for the names of the personnel from your office that will be attending the workshop. The course size is limited so please be prepared to provide the names of those attending when Lynn calls. Should you have any questions in the meantime, feel free to telephone her toll free (800) 356-0458.

We will keep you informed on additional details as they arise. Attached is the agenda and the list of instructors. We look forward to seeing you on January 9!

Happy Holidays!

J. Korbin Riley
Marketing Manager

1989 DISTRIBUTOR TRAINING SCHOOL

January 9-13, 1989

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Standard Oil
Engineered Materials Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio, 44139
216 349-6881

STANDARD OIL
ENGINEERED MATERIALS

TO: *See Below DATE: October 21, 1988

FROM: Tino Lopez COPY: *S. DeSutter
B. Gardner
C. Krauter

SUBJECT: Confirmation Scheduler School Planning Meeting

Just a note to remind you of our meeting on November 9th to finalize and assign the Scheduler School curriculums and to set deadlines for completion of assignments. I have set the time for 8:30 a.m. Attached is the curriculum framework developed to date.

Additionally, we need to obtain from you Charlie, a cost statement which includes meals and breaks, presentation aids (study manual, audio visual equipment etc), classroom rental, transportaion, tutor fees and all other pertinent costs.

If you have any questions please call me at 602-835-0103.

1989 TRAINING
SCHEDULER MARKETING REPS
JANUARY 9-13

A.	Plant Physiology	1/2 day;	Krauter
B.	Crop Water Stress Index		
	1. Theory of the Method	1/4 day	Gardner
	2. Comparison and Complement to Other Methods	1/4 day	Krauter
C.	Scheduler Operations		
	1. Intro Product Components	1/8 day	Lopez
	2. Running the Program	1/8 day	Lopez
	3. Sampling Techniques	1/4 day	Gardner/Krauter
	4. Data Analysis & Strategy	1/4 day	Gardner/Krauter
D.	Design A Monitoring Program		
	1. Design and Form Maps	1/8 day	Krauter
	2. Aerial Imagery	1/8 day	Verde
	3. Helping a Customer Plan	1/8 day	Gardner
E.	Computer Science	3/4 day	Krauter & Gardner
	1. Terminology and Nomenclature		
	2. DOS Operations and Commands		
	3. Touble Shooting Interfaces etc		
	4. New System Set-up		
F.	Company Policy	1/8 day	DeSutter
	1. Warranty		
	2. Repairs		
G.	Proffesional Selling Skills	1/2 day	DeSutter/Lopez
H.	CropLink ???		

Specific Cases — 2nd Day

Several Computers Link-up between Scheduler & P.C.

1 Day 8:00 - 8:30

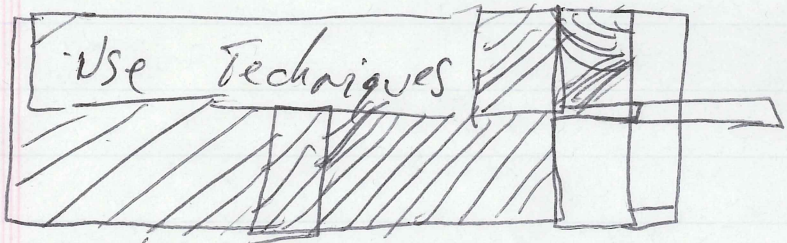
TO ½ day = 3½ hours
¼ day = 1½ hours
⅛ day = 1 hour

A Plant Physiology
- Transp.
- Photosyn.
- Hi-Pot. Irrig. Paper using the 1st 5-10% of soil moisture
- Integrating
- Irrigation Scheduling

¼ = 1½-2 hours (including ½ hr. break)

B. Theory of The Method
- History
- Paper (Jackson) To Review History
- Technical Theory
-

C. Use Techniques



- Kraatter - Specific Crop
  Gardner - General Pattern Analysis

TINO LOPEZ
STANDARD OIL ENGINEERED MATERIALS COMPANY
1506 E. FAIRFIELD
MESA, AZ 85203
(602) 835-0103
FAX: (602) 461-8669

TO: S. DeSutter & B. Gardner

LOCATION: Solon, OH.

FROM: T. Lopez

NUMBER OF PAGES TO FOLLOW: 2

ADDITIONAL COMMENTS:

1. Please make copy for DeSutter and or Gardner.

2. Confirmation Scheduler School Planning Mtg.

Standard Oil
Engineered Materials Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio, 44139
216 349-6881

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ENGINEERED MATERIALS

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If you have any questions please call me at 602-835-0103.

1989 TRAINING
SCHEDULER MARKETING REPS
JANUARY 9-13

A.	Plant Physiology	1/2 day;	Krauter
B.	Crop Water Stress Index		
	1. Theory of the Method	1/4 day	Gardner
	2. Comparison and Complement to Other Methods	1/4 day	Krauter
C.	Scheduler Operations		
	1. Intro Product Components	1/8 day	Lopez
	2. Running the Program	1/8 day	Lopez
	3. Sampling Techniques	1/4 day	Gardner/Krauter
	4. Data Analysis & Strategy	1/4 day	Gardner/Krauter
D.	Design A Monitoring Program		
	1. Design and Form Maps	1/8 day	Krauter
	2. Aerial Imagery	1/8 day	Verde
	3. Helping a Customer Plan	1/8 day	Gardner
E.	Computer Science	3/4 day	Krauter
	1. Terminology and Nomenclature		
	2. DOS Operations and Commands		
	3. Touble Shooting Interfaces etc		
F.	Company Policy	1/8 day	DeSutter
	1. Warranty		
	2. Repairs		
G.	Proffesional Selling Skills	1/2 day	DeSutter/Lopez
H.	CropLink ???		

10/12

Copy Chuck + Burson ✓

1/2 day A. Plant Physiology (CK)

½ day max.

docs: Krantz's class materials

1/2 day B[1] Crop Water Stress Index (Theory of the method) (BRG)

B[2] Comparision + Complement to other Methods (CK)

1/2 to 2/3 day C. Scheduler Operation (T.L.)

~~[redacted]~~ 1. Intro in to the Product Components (T.L.)

2. Running the program (T.L.)

3. Sampling techniques (BRG/CK)

4) Data analysis (BRG/CK)
(Strategy)

1/3 D. Design a monitoring program

1. Design + farm maps (Verdie/BRG/CFK)
Shelly Carl

2. Verdis Arial images ½ hr.

3. Helping a customer plan

E. Computer Science

2/3 to 1 day 1. Numerology + nomenclature

2. Iron Dos operators, commands
creating files, changing communications

3. Trouble shooting interfaces etc.

10/12

2/3 day F. Professional Selling Skills (TL + SCD)

G. Company Policy (SCD)+(TL)

= Guarantee

= Repair reputation

Jan.
Rome sched. 9-13

Add Crop link

7

CARBORUNDUM

The Carborundum Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio 44139

Telephone: 216 349-6881
Fax: 216 349-6397

December 19, 1988

Mr. Bronson Gardner
The Carborundum Company
P. O. Box 391316
Solon, OH 44139

Dear Bronson:

Just a note to keep you updated on the Distributor Training School to be held January 9-13 at the Center for Irrigation Technology, California State University, Fresno. PCA credit has been applied for and when we find out the exact number of hours available for credit we will let you know.

In addition,two California State University Fresno extension credit units are available for a cost of $60.00. The attendees that want credit will need to fill out a form and pay on the first day of training. Dr. Krauter will also need to have you write a short paper of some kind to serve as an evaluation. The course will be titled Plant Science 170T and is upper division (Junior/Senior level). The $60.00 cost is an estimate from the extension director but it should be fairly accurate. In a few more days we should have the exact cost pinpointed.

Attached is a map showing our training location at CIT on the corner of Barstow and Chestnut and the suggested lodging locations. Also enclosed for your convenience is another copy of the training course itinerary.

We look forward to seeing you after the holidays.

Merry Christmas,

J. Korbin Riley
Sales Distribution Manager

JKR/jmm
cc: C. Krauter
Enclosure

1989 DISTRIBUTOR TRAINING SCHOOL

January 9-13, 1989

California State University, Fresno
Center for Irrigation Technology

Day	Time	Subject/Activity	Instructor Location
Monday	12:00-1:15	Buffet Lunch	CIT
January 9	1:15-1:30	Introduction/Mission	DeSutter
	1:30-5:00	Plant Physiology	Krauter
	Evening	Open	
Tuesday	8:00-8:30	Continental Breakfast	CIT
January 10	8:30-10:00	Intro to the CWSI Theory	Gardner/Krauter
	10:15-12:00	Intro Product Components/ Running the Program	Riley
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Sampling Technique	Gardner/Riley (field location)
	3:00-3:15	Break	
	3:15-4:00	Classroom Discussion/Intro Croplink	Krauter
	4:00-5:30	Aerial Images/Farm Mapping	Verde Technologies
Wednesday	8:00-8:30	Continental Breakfast	CIT
January 11	8:30-9:30	Data Analysis	Gardner
	9:30-9:45	Break	
	9:45-11:00	Designing a Farm Program	Carl
	11:00-12:00	Comparison and Complement/ Other Methods	Krauter
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Field Sampling (Test)	
	3:00-3:15	Break	
	3:15-4:00	Review of Field Work	Krauter
	4:00-5:00	Downloading to a PC	Gardner
	Evening	Open	
Thursday	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Reviewing Previous Day's Results	Computer Lab
	9:30-9:45	Break	
	9:45-12:00	PC Lab/Software Programs	Krauter/Gardner
	12:00-1:15	Lunch	Faculty Dining Room
	1:15-3:00	Croplink/Field Applications	Maupin/CIT
	3:00-3:15	Break	
	3:15-5:00	User Panel	Carl
	7:00-9:00	Dinner/Carborundum	
Friday	8:00-8:30	Continental Breakfast	CIT
January 13	8:30-10:00	Putting It All Together I	DeSutter
	10:00-10:30	Break	
	10:30-12:00	Putting It All Together II	DeSutter

COURSE INSTRUCTORS

Dr. Charles Krauter	Professor, Irrigation Science California State University, Fresno
Steve Carl	President, CCT Corporation

The Carborundum Company, Instrument Technologies

Steven C. DeSutter	Manager
Bronson Gardner	Ph.D., Agricultural Meterologist
J. Korbin Riley	Marketing Manager
E. William Maupin	Sales Representative/Crop Link Product Specialist

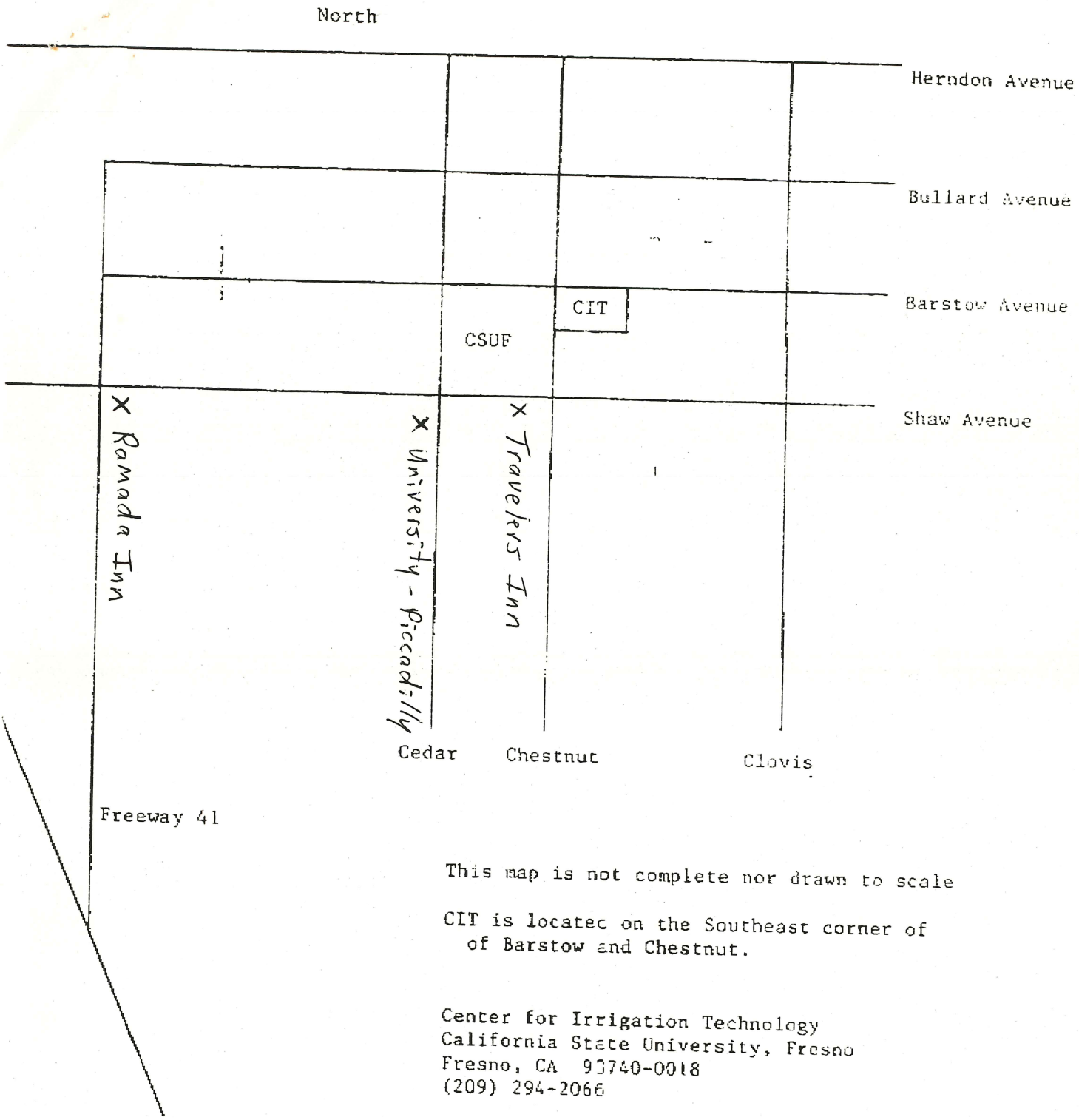
LOCAL ACCOMMODATIONS

Piccadilly (University location)
(209) 224-4200
$47 Single, $55 Double

Ramada Inn (Shaw Avenue Location)
(209) 224-4040
$49.28 Single, $55.44 Double

Travellers (Shaw Avenue location) One Block from CIT
(209) 294-0224
$29.06 Single, $33.54 Double

These are group rates through California State University and should be confirmed when reserving your room. As always, hotel rates are subject to change without notice.



This map is not complete nor drawn to scale

CIT is locatec on the Southeast corner of
of Barstow and Chestnut.

Center for Irrigation Technology
California State University, Fresno
Fresno, CA 93740-0018
(209) 294-2066

CARBORUNDUM

The Carborundum Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio 44139

Telephone: 216 349-6881
Fax: 216 349-6397

November 22, 1988

Dr. Charles Krauter
Department of Plant Science
Fresno State University
Fresno, CA 93740-0072

Dear Dr. Krauter:

I am finally getting around to summarizing our meeting of a couple of weeks ago. In the future please address any questions about the agenda to Korbin, Bronson or me as Mr. Lopez is no longer with our organization.

Following is my interpretation of the course schedule per our most recent revision. Please advise me if you see it any differently:

Deadline 31 December

1989 DISTRIBUTOR TRAINING SCHOOL
January 9-13, 1989
Center for Irrigation Technology

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Tuesday January 10	8:00-8:30	Continental Breakfast	CIT
	8:30-10:00	Intro to the CWSI Theory	Gardner/Krauter
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	3:00-3:15	Break	
	3:15-4:00	Classroom Discussion Intro Croplink	Krauter
	4:00-5:30	Aerial Images/Farm Mapping	Verde Technologies
	7:00-9:00	Dinner (Verde) (Steve Carl Follow-up)	

Manual

Aiming

Day	Time	Subject/Activity	Instructor Location
Wednesday January 11	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Data Analysis	Gardner
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	9:45-11:00	Designing a Farm Program	Carl
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	1:15-3:00	Field Sampling (Test)	
	3:00-3:15	Break	
	3:15-4:00	Review of Field Work	Krauter
	4:00-5:00	Downloading to a PC	Gardner
	Evening	Open	
Thursday January 12	8:00-8:30	Continental Breakfast	CIT
	8:30-9:30	Reviewing Previous Day's Results	Computer Lab
	9:30-9:45	Break	
	9:45-12:00	PC Lab/Software Programs	Krauter/Gardner
	12:00-1:15	Lunch	Faculty Dining Room
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Friday January 13	8:00-8:30	Continental Breakfast	CIT
	8:30-10:00	*Putting it All Together I	DeSutter
	10:00-10:30	Break	
	10:30-12:00	*Putting it All Together II	DeSutter

P.C. / DOS / R+D Programs

* Video taped selling exercises, coaching on selling skills to implement the fundamentals taught during the week.

Please agree or offer amendments to this schedule so it can be finalized

Best regards,

Steven C. DeSutter
Manager, Sensor Technologies

SCD/lb

cc: S. Carl
B. R. Gardner
J. K. Riley
E. W. Maupin

You are

cordially invited to

1989 DISTRIBUTOR TRAINING SCHOOL

For Distributors of the

Scheduler™
Plant Stress Monitor

Monday, Noon, January 9

through

Friday, Noon, January 13

at the

Center for Irrigation Technology
California State University, Fresno

CARBORUNDUM

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Sensor Technologies
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Telephone: 216 349-6881
Fax: 216 349-6397

December 9, 1988

DISTRIBUTOR TRAINING SCHOOL

Mr. Bronson Gardner
The Carborundum Company
P. O. Box 391316
Solon, OH 44139

Dear Bronson:

Even though we are tieing up our loose ends from 1988 just as you are, it's already time to start planning for next year! In order to kick the year off in a productive way, we are holding an intensive training workshop beginning at noon on Monday, January 9 through noon on Friday, January 13 at California State University, Fresno for our west coast distributing partners. This is an important opportunity for you to receive comprehensive training on the Scheduler[R] Plant Stress Monitor and the new Croplink[TM] Crop Monitoring System product lines. The course will cover plant physiology, the Crop Water Stress Index, how to design a farm use program, and key selling skills helping you put it all together.

Each day a continental breakfast and buffet lunch will be provided as well as a group dinner on Thursday evening, January 12. Transportation and lodging will be your responsibility. We have provided a list of local accommodations to assist you.

We at Carborundum feel that the workshop will be extremely beneficial for you and because we feel so strongly the first two people attending the workshop from your business will attend for **FREE**. Each additional person over the limit of two will be charged a $200.00 tuition fee. Lynn Bucknell, our Sales Correspondent, will be telephoning you in the next few days for the names of the personnel from your office that will be attending the workshop. The course size is limited so please be prepared to provide the names of those attending when Lynn calls. Should you have any questions in the meantime, feel free to telephone her toll free (800) 356-0458.

We will keep you informed on additional details as they arise. Attached is the agenda and the list of instructors. We look forward to seeing you on January 9!

Happy Holidays!

J. Korbin Riley
Marketing Manager

1989 DISTRIBUTOR TRAINING SCHOOL

January 9-13, 1989

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Center for Irrigation Technology

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Standard Oil
Engineered Materials Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio, 44139
216 349-6881

STANDARD OIL
ENGINEERED MATERIALS

TO: *See Below DATE: October 21, 1988

FROM: Tino Lopez COPY: *S. DeSutter
B. Gardner
C. Krauter

SUBJECT: Confirmation Scheduler School Planning Meeting

Just a note to remind you of our meeting on November 9th to finalize and assign the Scheduler School curriculums and to set deadlines for completion of assignments. I have set the time for 8:30 a.m. Attached is the curriculum framework developed to date.

Additionally, we need to obtain from you Charlie, a cost statement which includes meals and breaks, presentation aids (study manual, audio visual equipment etc), classroom rental, transportaion, tutor fees and all other pertinent costs.

If you have any questions please call me at 602-835-0103.

1989 TRAINING
SCHEDULER MARKETING REPS
JANUARY 9-13

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D.	Design A Monitoring Program		
	1. Design and Form Maps	1/8 day	Krauter
	2. Aerial Imagery	1/8 day	Verde
	3. Helping a Customer Plan	1/8 day	Gardner
E.	Computer Science	3/4 day	Krauter & Gardner
	1. Terminology and Nomenclature		
	2. DOS Operations and Commands		
	3. Touble Shooting Interfaces etc		
	4. New System Set-up		
F.	Company Policy	1/8 day	DeSutter
	1. Warranty		
	2. Repairs		
G.	Proffesional Selling Skills	1/2 day	DeSutter/Lopez
H.	CropLink ???		

Specific Cases — 2nd Day

Several Computers Link-up between Scheduler & P.C.

1 Day 8:00 - 8:30

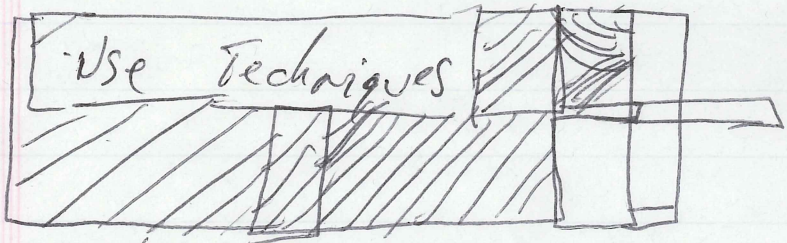
TO ½ day = 3½ hours
¼ day = 1½ hours
⅛ day = 1 hour

A Plant Physiology
- Transp.
- Photosyn.
- Hi-Pot. Irrig. Paper using the 1st 5-10% of soil moisture
- Integrating
- Irrigation Scheduling

¼ = 1½-2 hours (including ½ hr. break)

B. Theory of The Method
- History
- Paper (Jackson) To Review History
- Technical Theory
-

C. Use Techniques



- Kraatter - Specific Crop
  Gardner - General Pattern Analysis

TINO LOPEZ
STANDARD OIL ENGINEERED MATERIALS COMPANY
1506 E. FAIRFIELD
MESA, AZ 85203
(602) 835-0103
FAX: (602) 461-8669

TO: S. DeSutter & B. Gardner

LOCATION: Solon, OH.

FROM: T. Lopez

NUMBER OF PAGES TO FOLLOW: 2

ADDITIONAL COMMENTS:

1. Please make copy for DeSutter and or Gardner.

2. Confirmation Scheduler School Planning Mtg.

Standard Oil
Engineered Materials Company
Sensor Technologies
6180 Cochran Road
P.O. Box 391316
Solon, Ohio, 44139
216 349-6881

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ENGINEERED MATERIALS

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H.	CropLink ???		

10/12

Copy Chuck + Burson ✓

1/2 day A. Plant Physiology (CK)

½ day max.

docs: Krantz's class materials

1/2 day B[1] Crop Water Stress Index (Theory of the method) (BRG)

B[2] Comparision + Complement to other Methods (CK)

1/2 to 2/3 day C. Scheduler Operation (T.L.)

~~[redacted]~~ 1. Intro in to the Product Components (T.L.)

2. Running the program (T.L.)

3. Sampling techniques (BRG/CK)

4) Data analysis (BRG/CK)
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2. Iron Dos operators, commands
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10/12

2/3 day F. Professional Selling Skills (TL + SCD)

G. Company Policy (SCD)+(TL)

= Guarantee

= Repair reputation

Jan.
Rome sched. 9-13

Add Crop link

SCHEDULER® KNOW HOW

A User's Guide Published for Successful Operation of the Scheduler® Plant Stress Monitor in Your Specific Crop Application

ALMONDS

INTRODUCTION

Crop use guides are based on the combined experiences and knowledge of university, private researchers and actual Scheduler® Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

SAMPLING TECHNIQUES

Follow these guidelines to assure successful field sampling:

- The sensor gun should view green vegetation in an area which is sunlit. Avoid shadows, sky, soil, wood, and brown leaves.
- Stand on the sunny side of a tree, with the sun at your back. Hold the sensor gun approximately parallel with the ground. If the tree does not have a fully closed canopy, aim the gun so that a second tree is directly in line with the target tree.
- Sample between 11:00 a.m. and 4:00 p.m. in the summer.
- Sample in the grove, not from roadways.
- Sunlight should be stable and shining brightly on the trees. When the sun is interrupted by a passing cloud, allow the trees to "warm" for 30 seconds after the sun reappears.
- Sample several areas of the grove.

CROP MANAGEMENT USING THE PLANT STRESS INDEX

It is common to see an increase of 1-2 stress units after a flood irrigation. This pattern is caused by lack of oxygen in the soil profile. This is especially evident in heavy soils. As drainage occurs, there is a rapid decrease in the index, it will remain low for a period of time and then gradually increase until the next irrigation.

Experience, consistency of use, proper aiming technique and effective data analysis are the keys to getting good results.

If the air temperature is below 85 degrees F, the index should remain less than 1 between bloom and full nut size.

Normal stress levels should be maintained between 0 and 3 during most of the growing season.

If air temperature is greater than 85 degrees F, the index may go up to 3.0 before irrigation between bloom and full nut size.

After full nut size, the index may go as high as 5 without damaging the crop.

Almonds/88-1

Copywright 1988, Standard Oil Engineered Materials Company, Sensor Technologies, P. O. Box 391316, 6180 Cochran Road, Solon, OH 44139 (216) 349-6881.

The information, recommendations, and opinions set forth herein are offered solely for your consideration, inquiry, and verification and are not, in part or total, to be construed as constituting a warranty or representation for which we assume legal responsibility.

SCHEDULER® KNOW HOW

A User's Guide Published for Successful Operation of the Scheduler® Plant Stress Monitor in Your Specific Crop Application

APPLES

INTRODUCTION

Crop use guides are based on the combined experience and knowledge of university, private researchers and actual Scheduler® Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

- Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

- Prepare to take readings:

  a. Make sure the lens is clean.
  b. Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Stable environmental conditions help assure proper readings.

Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

- Sample in the orchard, not from roadways. It is essential to move at least 50 feet into the orchard. Sample several areas.

- Aim at a spot at least 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- The sensor gun should view green vegetation in an area which is sunlit. Avoid shadows, sky, soil, wood and brown leaves.

- Stand on the sunny side of a tree, with the sun at your back. Hold the sensor gun approximately parallel with the ground. If the tree does not have a fully closed canopy, aim the gun so that a second tree is directly in line with the target tree.

- Sunlight should be stable and shining brightly on the trees. When the sun is interrupted by a passing cloud, allow the trees to "warm" for two minutes after the sun reappears.

- Aim at an area at least two seconds before you pull the trigger.

- At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

- To sample, move gun in a circular motion around an individual tree taking about 10-12 samples.

NORMAL INDEX PATTERNS ON APPLES

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation.

Moisture stress (high index readings) reduces the size of apples. With some varieties, total tonnage will be reduced by stress. With other varieties the effect of moisture stress on total yield may be small. The effect on total yield depends on whether or not stress causes blossoms to abort or fruit to drop. This is a variety-specific characteristic that is known by most growers.

SPECIFIC RECOMMENDATIONS

Index values should range between -3.0 and +3.0 and should generally be below 1.0. Irrigate when the index exceeds 2.0. Size reduction can be expected if the index exceeds 3.0 for an extended period of time.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Apples/89-1

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SCHEDULER® KNOW HOW

A User's Guide Published for Successful Operation of the Scheduler® Plant Stress Monitor in Your Specific Crop Application

CORN

INTRODUCTION

Crop use guides are based on the combined experiences and knowledge of university, private researchers and actual Scheduler[R] Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

PLANNING OBSERVATIONS

Determine a convenient sequence of fields to sample. Include in your sampling: (a) Recently irrigated areas, (b) Areas where soil moisture is monitored and (c) Areas where problems may occur.

Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean, (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

- Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Keep the sun at your back.

Hold the gun at least three feet above the soil, or two feet above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows. Tassels do not have a significant impact on the index.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON CORN

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 0.0) and moderate stress (2.0 to 3.0) between irrigations, resulting in average index values of 0.0 to 1.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Begin taking readings after the fifth leaf emerges. Measurements made prior to this time may be influenced by soil temperature. Aim at individual plants or "down the row" until a full canopy developes. Readings may be made from any elevated platform once the corn becomes tall. Examples of measurement platforms being used are center pivot towers, step ladders, and the roof or hood of pick-up trucks.

Irrigate when the index exceeds 2.0. Minimize the exposure of the crop to index values 3.0 or greater. Maximum irrigation efficiency is obtained when the stress index is maintained between 0.0 and 2.0.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Corn/89-1

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SCHEDULER® KNOW HOW

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COTTON

INTRODUCTION

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PLANNING OBSERVATIONS

Determine a convenient sequence of fields to sample. Include in your sampling: (a) Recently irrigated areas, (b) Areas where soil moisture is monitored, and (c) Areas where problems may occur.

Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean, and (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

Keep the sun at your back.

Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target

should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON COTTON

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 1.0) and moderate stress (2.0 to 4.0) between irrigations, resulting in average index values of 0.0 to 1.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

- Begin making readings after effective ground cover develops. Aim the gun at a point about 30 feet away to judge this.

Extensive research has shown that fields yielding in the three bale per acre range follow similar stress index patterns. A typical high yielding stress pattern is:

Event	Average Index Range At Irrigation (Schedule to Hit This Zone)	
50% first square	4-6	Note: Readings can vary at this stage due to soil influence on plant temperatures.
50% first bloom	2.5-4.5	
Peak bloom period	2.5-4.5	
50% first open boll	4-5	
Defoliation decision	4-6	For systemic defoliants
	6-8	For contact defoliants

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Cotton/89-1

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SCHEDULER® KNOW HOW

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FORAGE ALFALFA

INTRODUCTION

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PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

- Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

- Prepare to take readings:

  a. Make sure the lens is clean.
  b. Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

- Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

- Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

- Keep the sun at your back.

- Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

- Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- Aim at an area at least two seconds before you pull the trigger.

- Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

- At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON FORAGE ALFALFA

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 0.0) and moderate stress (2.0 to 3.0) between irrigations, resulting in average index values of 0 to 1 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Readings can be started two weeks after the last harvest, or as soon as a green canopy is established.

Irrigation is needed if the index consistently exceeds 2.0 after canopy is established. Avoid index values greater than 4.0 after the canopy is established.

Irrigation is not needed if the index is less than 1.0 one to two days before a cutting.

In general, the cooler the crop stays, the higher the yields and the better the quality.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Forage Alfalfa/89-1

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SCHEDULER® KNOW HOW

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GRAPES

INTRODUCTION

Crop use guides are based on the combined experiences and knowledge of university, private researchers and actual Scheduler® Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

- Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

- Prepare to take readings:

  a. Make sure the lens is clean.
  b. Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

- Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Aim at a spot about 30 feet from where you are standing if you positioned above the canopy. Otherwise, aim down a single row or at an individual plant. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under moderate windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions. Under extreme wind conditions (30 mph plus) the index readings may actually increase by 1-2 stress units.

SAMPLING TECHNIQUES

- The sensor gun should view green vegetation in an area which is sunlit. This requires that you take samples on the top portion of the the crop canopy on the "sunny" side of the row.

- Aim toward the sunny side of the vine, with the sun at your back.

- Before vine canopy closure occurs, stand 2-3 feet from the vine and aim at leaf clusters. Take at least 3 samples per vine and sample at least 3 vines for each area. If your objective is to measure the stress status of a single vine, then record at least 9 samples per vine. Sample leaves in the top 1/3 of the canopy. Avoid shaded leaves and gaps in the canopy.

- After canopy closure occurs, aim the sensor gun at the top 1/3 of the canopy. Stand 3-5 feet from the vine. You may aim at individual vines or "down the row" at a glancing angle 5-10 feet away. If you can stand above the canopy, aim across several rows and sample in a sweeping motion or aim "down the middle" of the row at areas up to 10 feet away. Be sure to avoid soil and vine support hardware. Check the owner's manual to estimate the size of your target area.

- Sample several areas of the vineyard.

- Aim at an area at least two seconds before you pull the trigger.

- Keep the sensor gun at least 3 feet above the soil.

NORMAL INDEX PATTERNS ON GRAPES

The optimum index for grapes depends on such factors as variety, root stock, and climate. Growers must establish target index values to meet their management objectives.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Grapes/89-1

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SCHEDULER® KNOW HOW

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JOJOBA

INTRODUCTION

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PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

- Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

- Prepare to take readings:

  a. Make sure the lens is clean.
  b. Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

- Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

- Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

- Keep the sun at your back.

- Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

- Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- Aim at an area at least two seconds before you pull the trigger.

- After canopy closure occurs, aim the sensor gun at the top 1/3 of the canopy. Stand 3-5 feet from the plants. You may aim at individual plants or "down the row" at a glancing angle 5-10 feet away. If you can stand above the canopy, aim "down the middle" of the row at areas up to 10 feet away. Check the owner's manual to estimate the size of you target area.

- At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON JOJOBA

The optimum index for jojoba depends on such factors as variety, root stock, and climate. Growers can quickly learn to establish target index values to meet their management objectives well.

Jojoba characteristically produces seeds (this year's crop) and flowers (for next year's crop) at the same time. This means that water stress can damage yields for two seasons. It is critical to avoid water stress in jojoba.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a rapid decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Irrigate to allow the stress index to fluctuate between -2.0 and +3.0 between June 1 and August 30. If the plant experiences stress levels above 3.0 for one or two days, no damage should occur. Sustained periods above 3.0 should be avoided.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Jojoba/89-1

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SCHEDULER® KNOW HOW

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POTATO

INTRODUCTION

Crop use guides are based on the combined experiences and knowledge of university, private researchers and actual Scheduler® Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

PLANNING OBSERVATIONS

Determine a convenient sequence of fields to sample. Include in your sampling: (a) Recently irrigated areas, (b) Areas where soil moisture is monitored, and (c) Areas where problems may occur.

Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean, and (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

Keep the sun at your back.

Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a no soil, sky, or shadows.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON POTATOES

When clouds move in front of the sun, the index will decease rapidly.

The index usually cycles between low stress (-2.0 to 0.0) and mild stress (0.0 to 1.0) between irrigations, resulting in average index values of around 0.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Begin taking readings after effective ground cover develops. Aim the gun at a point about 30 feet away to judge this.

Potatoes are extremely sensitive to water stress. Water stress during tuber growth rapidly leads to a loss in tuber grade and internal tuber quality. As index values increase, yields decline, specific gravity declines and market grade rapidly deteriorates. Index value should be less than 0.0 as much as possible. See Figure 1.

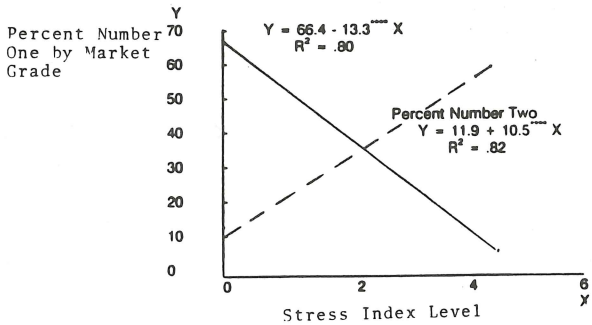

Figure 1: Relationship between Russet Burbank market grade and average crop water stress index, Malheur Experimental Station, Oregon State University, 1987 and 1988.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Potato/89-1

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SCHEDULER® KNOW HOW

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SEED ALFALFA

INTRODUCTION

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PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

- Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

- Prepare to take readings:

  a. Make sure the lens is clean.
  b. Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

- Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

Keep the sun at your back.

Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON SEED ALFALFA

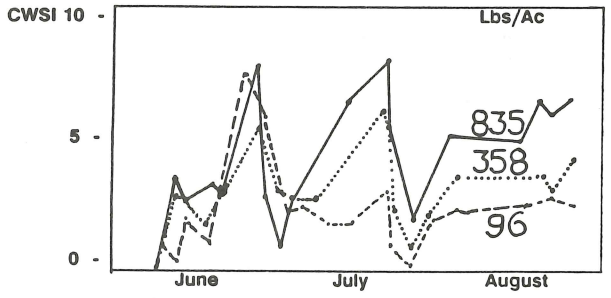
When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 1.0) and high stress (7.0 to 8.0) between irrigations, resulting in average index values of 5.0 to 6.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Research has shown that maximum yields are obtained when the stress pattern is similar to that given in Figure 1. The sawtoothing pattern of the stress index ranging between 0.0 and 9.0 (no stress to high stress) achieves a balance between stressing the crop to stimulate seed production and maintaining the vigor of the crop so that seeds can be produced.



CWSI Patterns And Associated Alfalfa Seed Yields, 1987. Malheur Experiment Station, OSU, Ontario, OR.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Seed Alfalfa/89-1

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SCHEDULER® KNOW HOW

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SORGHUM

INTRODUCTION

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PLANNING OBSERVATIONS

Determine a convenient sequence of fields to sample. Include in your sampling: (a) Recently irrigated areas, (b) Areas where soil moisture is monitored and (c) Areas where problems may occur.

Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean, (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

Keep the sun at your back.

Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON SORGHUM

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 0.0) and moderate stress (2.0 to 3.0) between irrigations, resulting in average index values of 0.0 to 1.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Begin taking readings after the fifth leaf emerges. Measurements made prior to this time may be influenced by soil temperature.

Aim at individual plants or "down the row" at a spot about ten feet away between the time the fifth and tenth leaves emerge.

After the head has emerged, readings may be made while standing on a center pivot tower at a target area up to 50 feet away.

After the heads emerge, aim at the leaves between the rows. The temperature of the heads can influence your readings.

Irrigate when the index exceeds 2.0. Minimize the exposure of the crop to index values 3.0 or greater. Maximum irrigation efficiency is obtained when the stress index is maintained between 0.0 and 2.0.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Sorghum/89-1

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SCHEDULER® KNOW HOW

A User's Guide Published for Successful Operation of the Scheduler® Plant Stress Monitor in Your Specific Crop Application

SUGAR BEETS

INTRODUCTION

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PLANNING OBSERVATIONS

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Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

Keep the sun at your back.

Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

Aim at an area at least two seconds before you pull the trigger.

Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON SUGAR BEETS

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 0.0) and moderate stress (2.0 to 3.0) between irrigations, resulting in average index values of 0.0 to 1.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

Begin making readings after effective ground cover develops. Aim the gun at a point about 30 feet away to judge this.

Sugar beets are very sensitive to plant stress and final yield losses if stressed for water prior to canopy closure. Keep the index as low as possible during this critical period.

After canopy closure, sugar beets become relatively tolerant of water stress. The index value that is selected for irrigation depends on management objectives. Irrigation can be initiated for maximum yields by irrigating when the index exceeds 1.0. A significant amount of water can be saved, with only a very slight effect on yield by delaying irrigation until the index is in the 3.0-5.0 range.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Sugar Beets/89-1

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SCHEDULER® KNOW HOW

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TOMATO

INTRODUCTION

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PLANNING OBSERVATIONS

- Determine a convenient sequence of fields to sample. Include in your sampling:

  a. Recently irrigated areas
  b. Areas where soil moisture is monitored
  c. Areas where problems may occur

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- Prepare to take readings:

  a. Make sure the lens is clean.
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FIELD CONDITIONS

Proper environmental conditions help assure proper readings.

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- Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

- Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

- Keep the sun at your back.

- Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

- Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- Aim at an area at least two seconds before you pull the trigger.

- Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

- At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON TOMATOES

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-3.0 to -1.0) and moderate stress (-1.0 to 0.0) between irrigations, resulting in average index values of -2.0 to -1.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

- Begin making readings after effective ground cover develops. Aim the gun at a point about 30 feet away to judge this.

Period (Days After Planting)	Expected Index Range
10-30	Plants too small to measure.
30-120	< 0.0
Harvest No. 1	0.0 to 2.0

In general, the index should remain below 0.0 most of the season.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Tomatoes/89-1

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SCHEDULER® KNOW HOW

A User's Guide Published for Successful Operation of the Scheduler® Plant Stress Monitor in Your Specific Crop Application

WATERMELON

INTRODUCTION: Crop use guides are based on the combined experience and knowledge of university, private researchers and actual Scheduler® Plant Stress Monitor owners. This guide provides the new user with information essential to the successful operation of the Scheduler.

PLANNING OBSERVATIONS

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Plan how Scheduler data will be recorded or downloaded to a computer. Software is available to assist you.

Prepare to take readings: (a) Make sure the lens is clean, (b) Let the gun adjust to the surrounding air temperature. This can take from 90 seconds to 10 minutes, depending on how hot or cold the gun was to begin with.

FIELD CONDITIONS

Proper environmental conditions help assure proper readings. Readings should occur no earlier than 30 minutes before solar noon. Solar noon occurs when the sun is directly south of you. Readings should occur no later than 3 hours after solar noon. At any rate, be consistent on when you take readings.

Take readings only in bright sunshine. When the sun is interrupted by a passing cloud, wait at least two minutes for the crop to warm up after the sun reappears.

Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

Sample in the field, not from roadways. It is essential to move at least 50 feet into the field. Keep the sun at your back. Sample individual plants or down a row until a canopy develops.

Hold the gun at least three feet above the soil. Be consistent. Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

Under full canopy take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type variance within the field.

At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON WATERMELONS

When clouds move in front of the sun, the index will decease rapidly.

The index usually cycles between low stress (-2.0 to 0.0) and mild stress (0.0 to 1.0) between irrigations, resulting in average index values of around 0.0 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

The recommendations below apply to watermelons grown in the central valley of California for harvest in early July.

Begin making readings after effective ground cover develops. Aim the gun at a point about 20 feet away to judge this. Readings on small plants may be influenced by soil temperature.

Average index values should remain between -2.0 and +1.0 on most days after June 1 up to harvest. The range in index values may be large in stressed areas, ranging from less that 0.0 to greater than 10.0. Normal index ranges should be between -2.0 and +2.0. We have grower reports that allowing the stress index to increase starting one week before harvest to stress levels of 3.0 to 4.0 at harvest results in detectable increases in melon sweetness due to a concentrating of sugars.

Index values above 3.0 on individual plants in areas with average index values below 1.0 may be caused by erroneous readings, or by stress developing due to other factors. Extremely hot air temperatures may create an evaporative demand beyond the capacity of a well-irrigated root system to handle.

Research Results: These results were obtained during the 1987 season at Fresno State University.

	Non-Stressed Watermelons				Stressed Watermelons			
Date	Air Temp(max)	Avg Index	Min Index	Max Index	Avg Index	Min Index	Max Index	
June 4	90.1	1.5	0.1	3.0	0.7	-2.0	3.5	
June 8	89.8	2.8	1.6	5.1	0.5	-2.1	3.1	
June 12	93.3	-0.4	-1.7	1.0	-0.6	-2.1	3.1	stress trt begins
June 15	79.7	-0.3	-2.7	1.3	2.6	0.0	6.4	
June 19	89.9	-2.4	-3.5	-1.1	7.7	4.4	11.5	
June 22	83.3	-2.1	-2.5	-1.5	7.4	6.1	8.3	
June 24	96.3	-0.3	-1.5	0.9	4.4	1.6	8.6	
June 26	96.9	2.7	-1.2	6.1	4.1	1.8	8.4	
June 29	86.7	0.7	-0.1	1.8	1.1	-1.8	4.6	
July 1	87.3	-0.5	-1.9	1.5	5.1	3.8	8.4	
Harvest:	64,771 lbs/acre 10.68% sugar				20,420 lbs/acre, 9% sugar			

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Watermelon/89-1

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WHEAT

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PLANNING OBSERVATIONS

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  c. Areas where problems may occur

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- Low wind (less than 10 miles per hour) speed is preferable. When readings are made under high windspeed conditions, the index readings may be 1-2 stress units lower than under low windspeed conditions.

SAMPLING TECHNIQUES

- Sample in the field, not from roadways. It is essential to move at least 50 feet into the field.

- Keep the sun at your back.

- Hold the gun at least three feet above the soil, or one foot above the top of the canopy. Be consistent.

- Aim at a spot about 30 feet from where you are standing. Avoid soil (often very hot), the sky (too cold), and shaded areas (too cool). Use your eyes: Your target should always be an area that (visually) appears as green, sunlit vegetation, with a minimum of soil, sky, or shadows.

- Aim at an area at least two seconds before you pull the trigger.

- Take 10-20 readings per location in a sweeping motion. Sample more than one location per field to get a good average. Actual number of locations sampled will depend on size of field and amount of soil type varience within the field.

- At your first sample location, take repeated readings until the averages of consecutive samples are within 0.5 index of each other.

NORMAL INDEX PATTERNS ON WHEAT

When clouds move in front of the sun, the index will decrease rapidly.

The index usually cycles between no stress (-1.0 to 0.0) and moderate stress (2.0 to 3.0) between irrigations, resulting in average index values of 0 to 1 between irrigations.

It is common to see an increase of 1 to 2 stress units after a heavy irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. Then there is a decrease in the index as drainage occurs. The index will remain low for a period of time and then gradually increase until the next irrigation or rainfall event.

SPECIFIC RECOMMENDATIONS

- Irrigate when the index exceeds 2.0. Minimize the exposure of the crop to index values 3.0 or greater.

- Maximum irrigation efficiency is obtained when the stress index is maintained between 0.0 and 2.0.

Consistent methods of planning, preparation, consistency of use, aiming techniques, and effective data analysis are the keys to getting good results.

Wheat/89-1

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Lesson Rewrite: - Good data

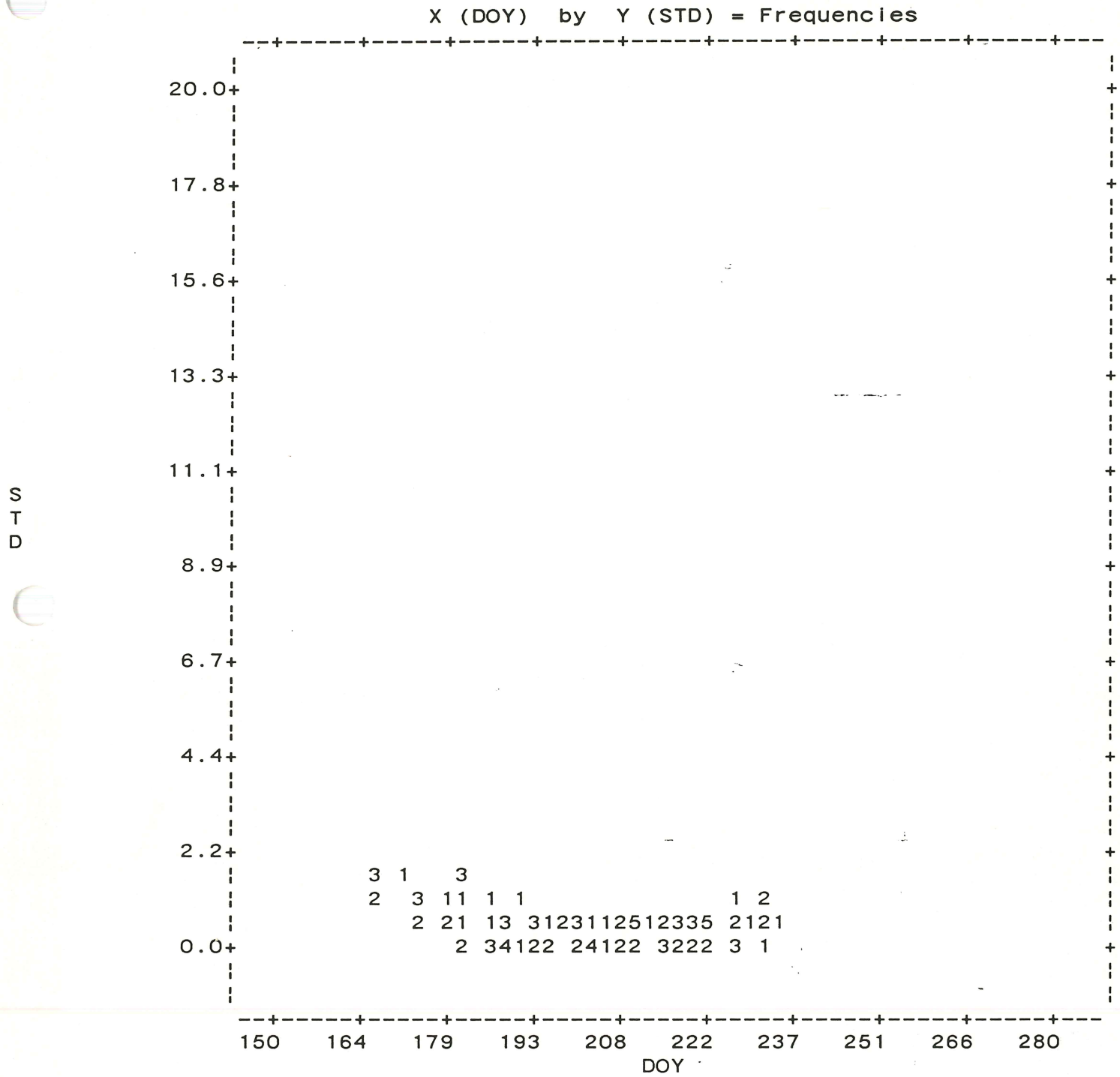
1) Effect of Clouds on the early
2) time of day reminder
3) Variability of Temperature
   a) indicates poor data
      - example of 2 ways
   b) indicate others

4) Techniques for Avoiding poor data
   - Bill Zimmerman techniques:
      a. Do multiple Samples 5.0, 4.2, 3.0 → 2.0, 2.1, 2.0 etc
      b. 15 day history graph - compare today's reading with last one
      c. watching T_A stability

5)

Getting good data first | 1) Air Temp patterns - equilibration
2) plant temp variability
3) Bill Zimmerman technique

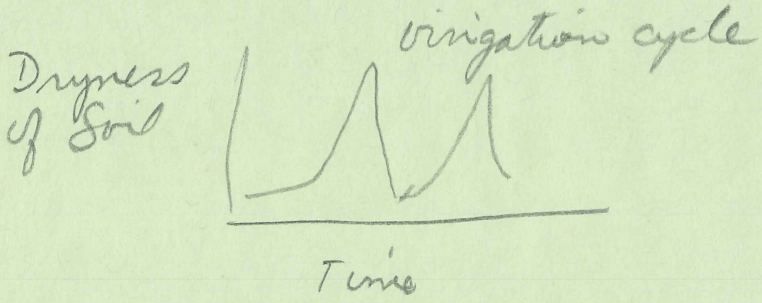
Figure 1. Standard deviation of crop temperatures at a commercial cotton site near Lemoore, Calif, 1988.

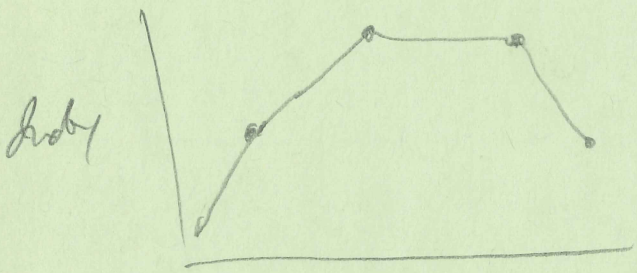


Introduction

1) pattern of index after flood irrigation

2)





"Normal Rule"
- index moves 4 points between irrigation cycles
- watch out for this

Reasons
a. not enough water (Stress)
b. hardware
c. too much water
d.

Drip Irrigation

1-2 Index units range (Charlies)

the reason Schedule can be used on drip: Is the time/volume sufficient

Soil Moisture

a) water content in the soil
(How much water) -- if properly calibrated
- takes more knowledge to interpret
soil moisture meters/devices than a
Scheduler. (neutron probe)(Hand sampling)
needs calibration

b) Water potential - tensiometer / resistance blocks
relates better to the direct functioning
of the plant

example Readings

tensiometer = 60] advantage - number is
resistan block = 120] repeatable for a crop
& variety.

neutron probe = 0.7 - how much water, if calibrated (had to do)

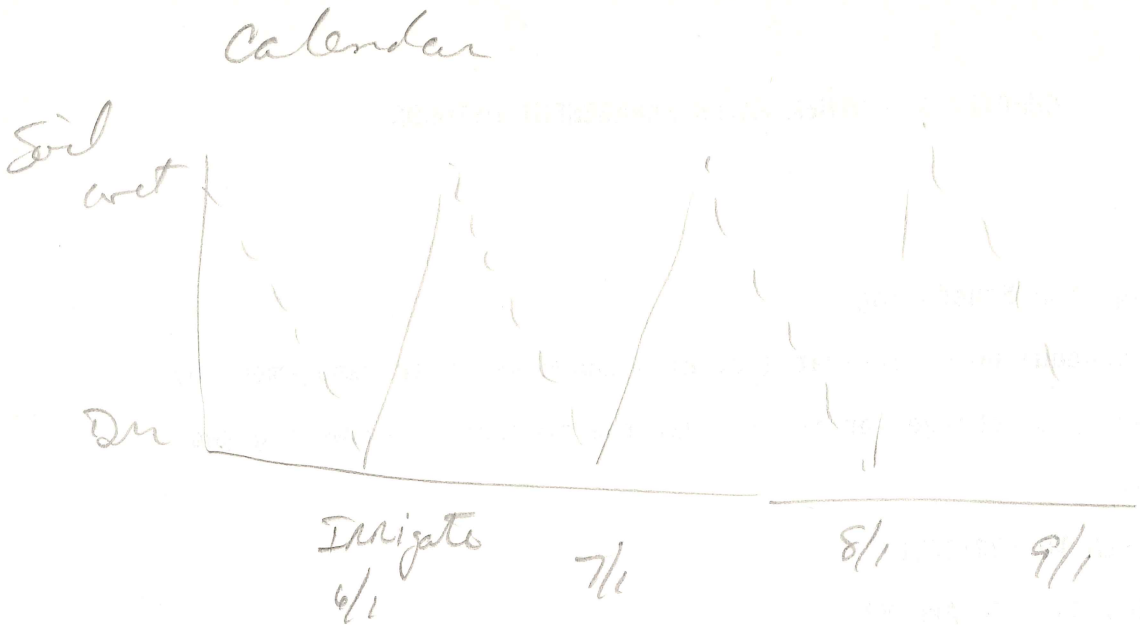
~~Interpretations~~

limitation - tensiometer only works in the
0 - 1 Bar range. - wet Range only

resistoral blocks → for dry & medium dry soil

Problem: Sample Size
needed - 1 set (2 oz) for 20 acres
for 300,000,000 lbs of soil.

Therefore, you need a Scheduler
to compare with.


Calendar
Soil
wet
Dr
Irrigate
6/1
7/1
8/1
9/1

Site Selection Problems

How good is the site?
- especially on drip irrigation.

Two methods serve as a cross-check to increase reliability.

Any way of double checking the ET estimate is required

THE CARBORUNDUM COMPANY

1989 DISTRIBUTOR TRAINING SCHOOL

January 9-13, 1989

Center for Irrigation Technology

Fresno State University

Fresno, California

COURSE OUTLINE

		Instructor
1.	Plant Physiology	Charles Krauter
2.	CWSI Theory	Bronson Gardner
3.	Product Components	Korbin Riley
4.	Sampling Techniques (Field Work)	Gardner/Riley
5.	Discussion/Introduction to Croplink	Charles Krauter
6.	Aerial Images/Farm Mapping	Verde Technologies
7.	Data Analysis	Bronson Gardner
8.	Designing a Farm Program	Steve Carl
9.	Comparison with Other Methods	Charles Krauter
10.	Field Sampling (test)	Staff
11.	Downloading to a P.C.	Bronson Gardner
12.	Review of Field Results	Staff
13.	PC Lab/Software Programs	Krauter/Gardner
14.	Croplink/Field Applications	Bill Maupin
15.	User Panel	Steve Carl
16.	Putting It All Together	Steve DeSutter

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6. Aerial Images/Farm Mapping.....Verde Technologies

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CHAPTER 1 - PLANT PHYSIOLOGY

HIGH POTENTIAL IRRIGATION BENEFITS CROP PRODUCTION

By: Charles F. Krauter

1.1 Water Management Strategy

High potential irrigation is a type of irrigation scheduling or management that will result in maximum crop production under conditions where water stress is commonly a problem. The term refers to the fact that a small amount of the water in the soil after an irrigation is attracted to the particles by a very weak chemical bond. In thermodynamic terms the water has a high, chemical potential. This water can be taken up by the plant roots very easily and at a rapid rate so the plant will not be water deficient or stressed even in a very hot, dry climate. When the high potential water from the soil has been absorbed, the remaining soil water, with a lower potential, will be more difficult for the plant to take up. That will result in difficulties for the plant when the rate of water loss from the leaves is high. High potential irrigation strategy consists of very frequent applications to maintain the soil water content at a point high enough to ensure that some high potential water is always available to the crop root system.

Special techniques and irrigation methods will be necessary to keep the potential of the soil water high enough to avoid stress as much as possible. The system must be able to apply a small amount of water in a very even or uniform manner to the field on a frequent schedule. The fact that the plant can only be allowed to take a small

amount of the soil water before stress occurs means the system must be able to reapply that small amount in an irrigation. Most surface irrigation methods such as furrow and border-check cannot accurately apply an amount as small as 1 cm of depth. If a furrow system cannot apply less than 10 cm of water and the soil can only hold 1 cm then there will be an excess that is wasted and may saturate the soil for a long period and could encourage a variety of soil pathogens. The frequency of application can be an even more difficult problem. It would take an unreasonably large water source to flood an entire field in a day or two even if the application could be limited to the small amount required. Many sprinkler systems that could apply the light irrigation amount will take too long to cover the field if a few laterals of sprinkler line must be moved by hand across the width of the acreage. An additional problem is one of coordination with other cultural practices. If the irrigation system must apply water daily, then it will have to work within the constraints of fertilization, pest management, and other activities in the field. Ideally, the system should be capable of water application during these other cultural practices. The alternative is to be able to apply the daily irrigation in a short time so that the rest of the cultural activity can then take place.

Irrigation methods that are adaptable to high potential irrigation management would be most drip/trickle systems and some types of sprinklers. The most useful sprinkler system would be either a permanent, solid set system or one of the mechanical move systems that can travel over the field in a day or two. The solid set sprinklers can cover the entire field at one time or in a few sets that quickly follow each other with good uniformity. The center pivot or lateral

move system is ideal for high potential because they are usually designed to cover the entire field in about 24 hours. Drip irrigation systems are very adaptable to this type of irrigation management. They apply water in very small, uniform amounts and seldom interfere with other field activities. Proper scheduling techniques for drip systems are essentially the same as high potential water management even in mild climates when the benefits are not so important. When drip systems are used for long periods of application at infrequent intervals in the manner that flood systems are often operated, there can be problems of saturated soil diseases as well as the loss of the benefits of high potential irrigation.

High potential irrigation benefits crop production because it is the best way to avoid the reduction of crop growth due to water deficiency in the leaf. A water deficiency in the plant (stress) will restrict the rate of an important process that occurs in every leaf, photosynthesis. The growth of a crop and the yield that can be harvested from it are primarily a result of the amount of photosynthesis that the plant is able to accomplish during its season. If the proper variety is planted, if the correct nutrients are present or added as fertilizer, if pest and disease problems are controlled and if there is sufficient soil water, then the photosynthetic process in the leaves will be able to optimize the production of energy for plant growth. The photosynthesis process requires light for energy which is used to combine a small amount of water from the soil with carbon dioxide from the air to make sugars which are then used by the plant as energy for growth in the same fashion that animals use sugars and other carbohydrates from food.

Photosynthesis can be limited by the amount of light but the usual problem of crops in irrigated agriculture is the supply of carbon dioxide from the air. The amount of water required for photosynthesis is a very small part of the amount of water that the plant takes up and it could be supplied even when the soil was quite dry. The carbon dioxide, however, is absorbed through small openings in the leaf surface called stomata. When the stomata are open to allow the intake of carbon dioxide, water inside the leaf will evaporate and be lost through the same opening. This is a normal process called transpiration. Most of the water taken up by the root system of a crop plant is to replace the water lost due to transpiration. The magnitude of transpiration will depend on how hot, dry and windy the air is around the leaf. If transpiration is more rapid than the rate of water uptake by the roots then the stomata will begin to close in order to preserve the moisture still inside the leaf. The closure of the stomata while necessary to prevent dehydration of the leaf will also restrict the absorption of carbon dioxide and photosynthesis will be reduced. The practice of high potential irrigation will keep the soil water at a level that will allow the highest possible uptake rate in order to match the high rates of transpiration.

Water uptake by the plant roots is a complex process that is affected by a number of factors but particularly by the amount of soil water present. There is a maximum amount of water that can be stored by a soil and taken up by the root system of a plant. When the amount of water in a soil is at or close to this maximum it is easy for the plant to take up large amounts of water to match high rates of transpiration and prevent water stress. As the soil becomes drier, not only must the water move farther to reach the root surface but also the

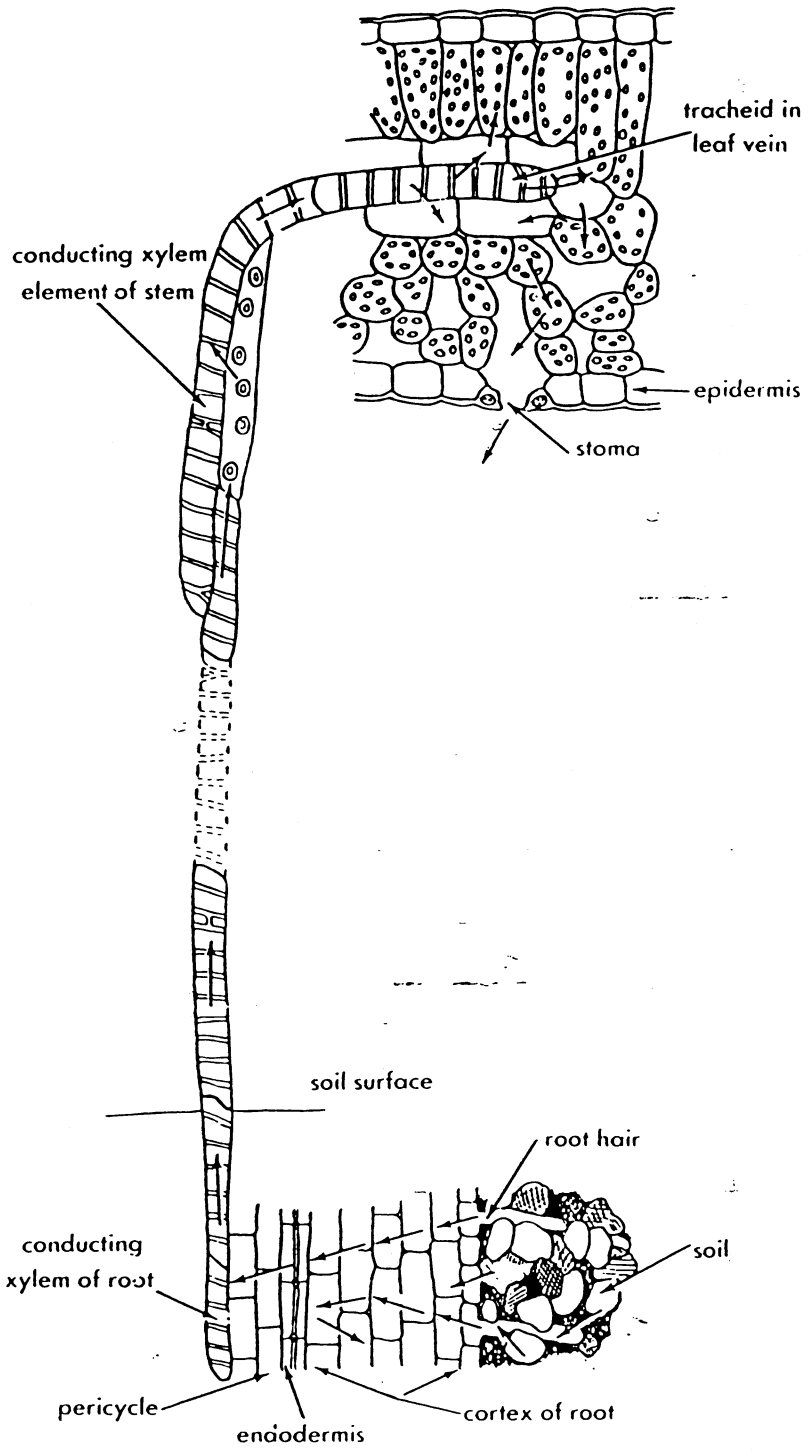

Fig. 11.6. Diagram showing entry of water from the soil to the root hair and its path of movement through the plant to parenchyma leaf cells, then escaping as water vapor into intercellular spaces, from which it passes to the atmosphere, mainly through stomata.

rate at which it moves is restricted by the increasing strength of molecular bonding between the soil particles and the remaining water. The increased bonding causes the reduction of the soil water potential and as it increases, the rate of water uptake by the roots of the plant is decreased. Water stress is therefore the most common when transpiration is high and large amounts of water must be taken up from the soil. Eventually, the water uptake reduces the water content of any soil to the point where the potential of the remaining water is lowered to the point where the plant cannot take up enough to match the transpiration loss and so the stomata close and restrict the carbon dioxide supply to the leaf.

1.2 Soil Water And Uptake By The Plant Roots

The soil holds the water that can be taken up by plant roots as a film or layer of water on the surface of each particle. The amount of water that a soil can contain is related to the amount of particle surface area of that soil. The surface area depends upon the size of the particles, referred to as the soil texture. Large particles, sandy soils, have large spaces or pores and relatively little surface area compared to those made up of smaller particles, silt and clay soils. The layer of water on the particle surface will be the same thickness regardless of the size of the particle or the pore space so soils with more surface area can hold more water. The water is held in the film by the force of attraction between the molecules of water and the oxygen molecules in the mineral structure of the particle. The water at the bottom of the layer next to the particle surface is held with a very strong attraction, therefore it has a low potential. The water at the top of the layer, away from the particle surface, is held by a weak

force which means it is subject to movement due to attraction by a stronger force. The stronger force would be a point where the water potential is lower such as near a root surface.

When water is applied to a soil in an irrigation or during rainfall the pores between the particles are initially filled with water, a condition called saturation. Most soils are about half particles and half spaces so the water content when the pores are saturated is about 50% of the soil volume. Saturation is not a desirable condition for plant growth because the roots of most crops need oxygen from soil air which is not present in saturated soil. Fortunately, the force of gravity is stronger than the attraction between the particle's surface and the water farthest from it in the middle of the pore. In other words the water potential in the pore's center is so high the water will not stay in the pore. If there is space below the saturated soil, gravity will drain the free water down deeper where it will eventually find drier soil that will hold it in the layer on the particle surface. There is a point where the layer of water on the particle is just thin enough that the water is attracted to the mineral with a greater force than that of the gravity trying to pull it down out of the soil pore. That condition is a stable, maximum water content called field capacity. In an irrigation, the top part of the crop root zone is saturated during water application then the excess water drains due to gravity to lower depths where the soil is dry. In the ideal irrigation, this drainage would occur until the soil was wet to field capacity just down to the bottom of the root zone.

At field capacity, the water in the layer on the particle surface is held with just enough force to prevent its movement due to gravity. The plant root, however can attract the water molecules in much the

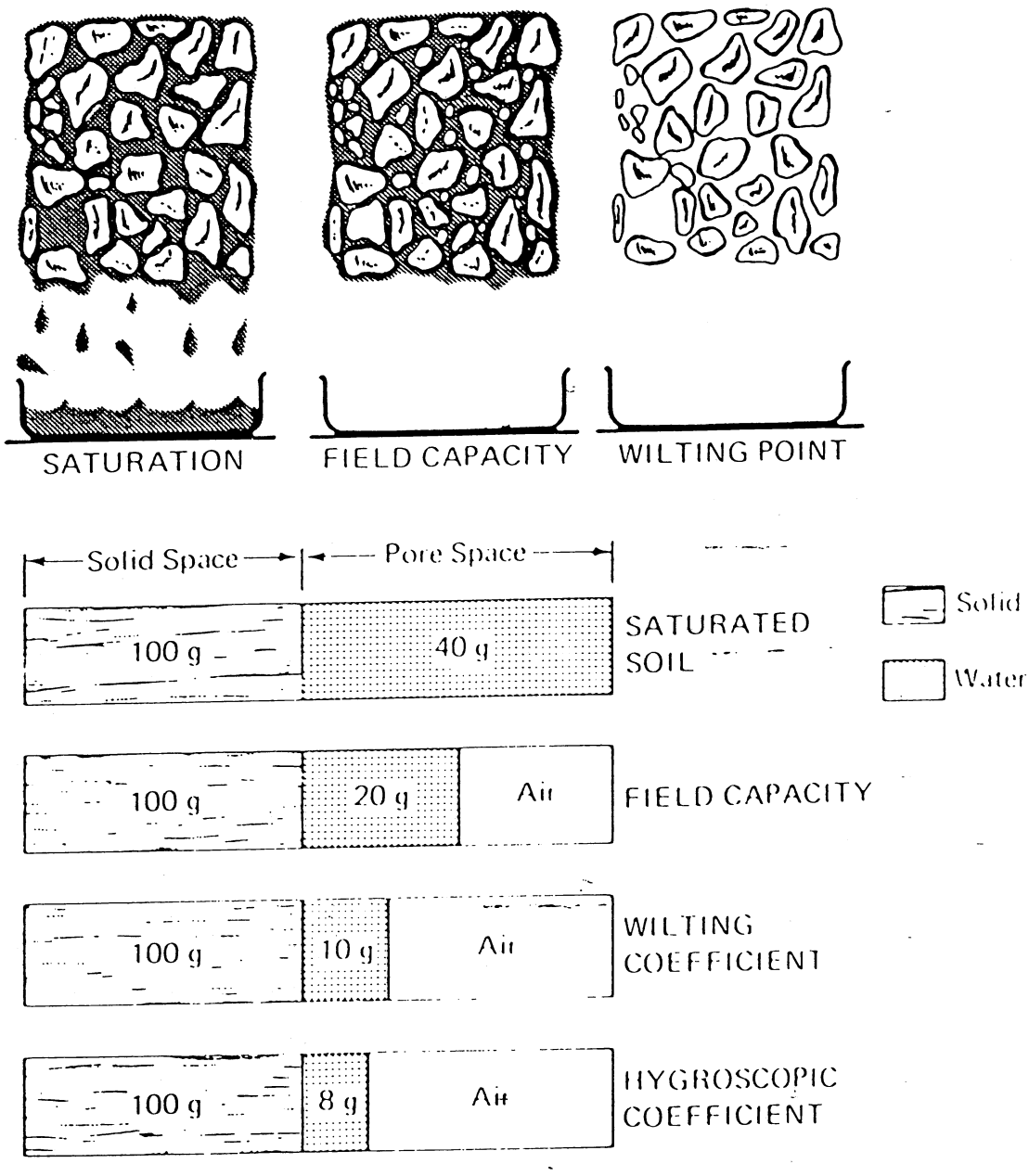

FIGURE 7:20. Volumes of solids, water, and air in a well-granulated silt loam at different moisture levels. The top bar shows the situation when a representative soil is completely saturated with moisture. This situation will usually occur for short periods of time during a rain or when the soil is being irrigated. Water will soon drain out of the larger or *macropores*. The soil is then said to be at the *field capacity*. Plants will remove moisture from the soil quite rapidly until the *wilting coefficient* is approached. Permanent wilting of the plants occurs at this point even though there is still considerable moisture in the soil (wilting coefficient). A further reduction in moisture content to the hygroscopic coefficient is illustrated in the bottom bar. At this point, the water is held very tightly, mostly by the soil colloids. [*Upper drawings modified from Irrigation on Western Farms published by the U.S. Departments of Agriculture and Interior.*]

same way as they are attracted to the soil particles. The cell walls of the root tissue are made of cellulose which contains oxygen and other atoms that attract the hydrogen in the water molecule. There is, therefore, a layer of water on the surface of the root cells just like that on the soil particles. The difference is that the water on the root cell wall disappears into the root because the water potential inside the plant is lower than in the soil. As the water film on the root decreases, its water potential decreases and pulls water from the thicker films on the adjacent soil particles. As long as the transpiration process continues, the root will pull water first from the nearby soil pores and then, as they are depleted, water will flow toward the lower potential from the high potential (field capacity) pores farther away from the root surface. In theory, water can be pulled from several centimeters to the root surface but in fact the rate at which it can move through the soil decreases with the distance that it moves and the water content of the soil. A plant can only pull water from the thin layers of dry soil in an amount that will allow a minimum level of metabolism that will just keep it alive. This driest water content of the soil is known as the wilting point. Maximum growth rate demands far more water uptake and that is only possible where the water is drawn from nearby soil pores and moves easily in the thick water layers in a soil at a relatively high water content. Maximum growth in hot, dry climates where the transpiration rate is high may only be possible when the water can move easily through the soil to the root at the high potential of field capacity. As soon as the soil begins to dry the rate of movement decreases until water movement from the soil cannot keep pace with the transpiration losses from the leaves and the plant begins to stress.

1.3 Salinity

Salinity is a problem that is widespread in irrigated agriculture though it is not always apparent. High potential irrigation practices can minimize its effects and are the simplest way to manage the problem. Salinity is the concentration of dissolved substances contained in the soil water that the roots of the crop must absorb. Water is an excellent solvent. It will dissolve small amounts of materials from the rock and soil of the watershed where it first falls as rain or snow, from the streambeds if it is flowing or from the matrix of the aquifer if it is ground water. It dissolves the minerals of the soil and, of course, it dissolves the applied agricultural chemicals such as pesticides and fertilizers. The solution in the pores of the soil is much more than just water molecules and it is to the benefit of the plant that this is so. The nutrients that the plant needs to take up for growth must be in dissolved form for the roots to absorb them. Unfortunately, there is often much more dissolved in the soil water that the plant does not need and that may interfere with the uptake of water. These dissolved substances are not merely floating around in the water, they are attracted to the water molecules in the same fashion that the soil particles and root cell tissue reacts with the water. Each molecule of dissolved compound is surrounded by layers of water molecules that are attracted to it just as though the molecule was a tiny soil particle. The effect of a large concentration of dissolved material, a high salinity, is to decrease the water potential in the soil pore. This makes it more difficult for the plant to take up the water even at field capacity. The result of a significant level of salinity is to make the soil seem to be at a lower water content

with regard to the plant root and water stress will occur more easily and more often.

While all soil water contains some salinity, most soils do not contain enough to significantly affect water uptake. Desert soils, those that have developed in dry climates and soils that are in low areas where significant amounts of surface drainage accumulated and evaporated are more likely to have excessive salinity. The water used for irrigation will add salinity to a soil if the management practices are not followed carefully. The plant can take up the water and exclude much of the dissolved salts so the salinity will accumulate in the root zone after successive irrigations. Proper irrigation management will keep the soil water at high potential, dilute the salts and include an extra amount of water that can pass through the root zone after it has been filled by the irrigation. This water that leaches through the soil will carry some of the accumulated salinity down below the reach of the roots preventing the build up of salinity to the point where it would affect water uptake in most instances.

1.4 Plant Growth and Transpiration

A plant grows like any other organism by increasing the number and size of the cells and by completing its reproductive phase. The seed or fruit that is harvested for most crops is the result of that reproductive phase and will require the normal development of the plant through the season to the flowering and fruiting that generally is the final stage of crop growth. All of the development from the first leaf to the last seed of the plant is the result of the hundreds of tissue synthesis or growth processes that occur in each of the millions of cells of even the simplest plants. These synthesis processes produce

proteins, fats, carbohydrates, and other substances from the simple minerals that the plant takes up from the soil. Each of these synthesis processes also requires energy. A plant cell cannot make a protein with the nitrogen and sulfur from the soil and carbon dioxide of the air without a source of energy to drive the biochemical reaction. The plant gets its energy from respiration, the "combustion" of simple sugars that it manufactures itself from water and atmospheric carbon dioxide in the photosynthesis reaction. Photosynthesis, like the other processes, must have an energy source but in its case, the reaction is be powered by light. The photosynthetic substance, chlorophyll, is able to capture energy from sunlight and change it to chemical energy by using it to join carbon, hydrogen and oxygen atoms together to make sugar molecules. Those sugars are then used in respiration to power the other synthesis processes of plant growth. Without the energy source from photosynthesis the growth processes cannot occur and the plant will not develop normally.

A common limitation of photosynthesis as described above is the supply of carbon dioxide from the atmosphere. It enters the leaf as one of the gasses of the air through tiny openings between the cells of the leaf surface called stomata. The stomata are surrounded by special cells of the leaf called "guard cells". These cells can open or close the stomata according to the amount of water in the leaf if there is sunlight present. The problem with the uptake of carbon dioxide through the stomata is that just inside the opening there are leaf cells with a high water content. Water will evaporate from those cells and the vapor will be lost through the stomatal opening (transpiration) at the same time as the carbon dioxide is entering by the same pathway. If the temperature is high, if the humidity of the air is low and

particularly if there is any wind, the rate of water vapor loss from the leaf will be rapid. The cells of the plant must maintain their high water content and so the water is replaced by uptake from the soil that is pulled in by the reduction of water content in the roots that is caused by the pull of water up the plant to restore the water lost in the leaves due to transpiration. If the rate of soil uptake is limited by water available only at low potential, the guard cells will react to the decreased supply of water to the leaf and close the stomata. The water loss from the leaf is reduced and dehydration of the leaf will be temporarily prevented but the supply of carbon dioxide to the chlorophyll is also restricted. Once the soil water is replenished and is again available at high potential, the stomata will open and growth will return to a maximum rate. The energy that the plant lost due to the temporary reduction of photosynthesis, however, can never be regained and the ultimate yield of the crop will have been reduced.

CHAPTER 2 - CWSI THEORY

2.1 A Simple Principle

CWSI (crop water stress index) is based on a simple principle. Any surface which is evaporating water at a high rate will be cooler than a similar surface that is not evaporating water as fast. You have probably experienced this principle many times. Recall a summer day at the beach. Before diving into the water, the summer sun made your skin feel warm. After you emerged from the water, you felt much cooler. Why? Simple. Your skin was evaporating water much faster when it was wet than when it was dry.

In a similar fashion, a leaf that is supplied with adequate water (non-stressed) will evaporate water faster than a leaf that has inadequate water (stressed). The result will be a difference in temperature between the non-stressed and the stressed leaves.

Back to the beach. If you felt too hot at the beach, you had two options to cool down, first, you could jump into the water, second, you could just walk into the shade. Isn't it amazing how much cooler you feel standing in the shade than when standing in the sun?

Plants react much the same way. Whenever a cloud moves in front of the sun, their temperature will also decrease. This means that whenever we want to compare stressed and non-stressed plant temperatures, we must be careful to make that comparison under the same sunlight conditions. It makes no sense to compare the temperature of a leaf in the shade with a sunlit leaf. The sunlit leaf will always be hotter. (Have you ever felt hotter in the shade than in the sun?)

2.2 Plant Temperature Research

Many scientists have studied plant temperatures during the last 150 years. A few were able to capture and understand the relationship between the plant's temperature and its overall health. Accurate temperature measuring devices were needed to advance the practical use of plant temperature. Only during the last 10 years were the first reliable hand-held infrared thermometers manufactured and commercially available to advance the use of this technology. Following is a summary of the major facts which have been reported.

1875 -- Thin leaves are cooler than thick leaves.

1905 -- Sudden increases in wind speed causes a decrease in plant temperature.

1915 -- The leaves of evergreens are much hotter than the air during winter (that's how they survive and photosynthesize).

1923 -- USDA researchers in Arizona showed that healthy leaves of various crop plants are cooler than the air during mid-day.

1929 -- The USDA confirmed that healthy cotton leaves can be 8 F or more cooler than the air.

1938 -- Garden plants can be as much as 14^{o}F below air temperature.

1052 -- The temperature of tomato and potato leaves are nearly the same.

1962 -- A scientist developed equations which showed that if a leaf remains motionless while the wind blows, its temperature is controlled by the windspeed, but if the leaf flaps, water evaporation controls leaf temperature.

1966 -- Infrared thermometers were first used to measure leaf and canopy temperature. The importance of solar radiation and time of day was emphasized.

1971 -- Leaf water content is correlated with leaf temperatures and relative humidity.

1973 -- Leaf water potential, stomatal resistance and leaf-air temperature differences are all correlated.

1973 -- A USDA scientist suggested using leaf-air temperature differences to schedule irrigations.

1981 -- USDA scientists developed the crop water stress index (CWSI).

In 1984, Standard Oil Engineered Materials Company (The Carborundum Company) conducted the first large scale field test of the CWSI concept. Prior to that time all the research had been conducted on small plots. Standard Oil Engineered Materials has been the driving force behind the technology transfer of CWSI from the theoretical domain of research scientists to the practical world of growers.

1984 -- First field test of CWSI concept.

1985 -- Multi-state field tests of CWSI.

1986-1988 -- Field tests continue. Simultaneously, the marketing/commercialization of the Scheduler was begun.

Between 1978 and 1988, the literature has exploded with information which demonstrates that canopy temperatures can be used to schedule irrigation and monitor crop condition on a wide variety of crops.

Standard Oil Engineered Materials has collected CWSI information from over 125 separate locations (experiments and grower fields). No other infrared thermometer company has been involved in CWSI research of this magnitude. We have conducted more CWSI research than the combined efforts of several university research departments.

The Scheduler is a new tool which helps answer questions that could never be asked prior to its invention. Plants are amazingly complex in their behavior and some questions will take years to answer. The important point is that sufficient knowledge exists to allow growers to benefit from monitoring the condition of their crops.

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Points to Remember

- **Non-stressed leaves are usually cooler than the air.**
- **Plant temperature is related to plant health. A plant that is "stressed" will (when the sun is shining brightly) will be hotter than a healthy "over-stressed" plant.**

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Do not be afraid to ask questions. Once you master the basics, you will start to feel comfortable with the Scheduler.

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2.3 Important Scientific Conclusions

The following statements summarize the conclusions of agricultural scientists concerning plant temperatures during the period 1929 - 1988. There is little room for doubt that leaf temperatures are considered very important.

"The facts suggest that the differences in yields are associated with the observed differences in their leaf temperatures." (Eaton and Belden, 1929).

"...transpiration invariably tends to lower the temperature of the transpiring leaf...." (Curtis, 1936).

"Leaf temperature relative to air temperature can be predicted..." (Waggoner and Shaw, 1952).

"Thus a sensitive measurement of the temperature difference between plant samples may provide an indication of transpiration differences." (Tanner, 1963).

"The temperature differences between well-watered and stressed crops should indicate a relative need for irrigation. Within large irrigation projects it should be possible to identify fields needing irrigation from crop canopy temperature information. Within individual fields plants in areas not irrigated adequately should stress sooner and have a higher canopy temperature than the nonstressed plants in well-watered surrounding areas." (Bartholic et al., 1972).

"On a given day, relative leaf water content and leaf temperature were highly correlated." (Carlson et al., 1972).

"Field studies at this laboratory have shown Tc-Ta to be a sensitive guide to changes in stomatal aperture, as measured by leaf resistance." (Ehrler, 1973).

"...measurement of Tc-Ta still appears adequate for assessing soil water status effects on crop vigor and signalling needed irrigation ..." (Idso and Ehrler, 1976).

"The results indicate that the temperature differences between the stressed and the unstressed plants arises primarily from differences in transpiration. It is further suggested that after proper calibration, plant temperature promises to be a reliable index for identifying crop water deficits and for optimizing irrigation scheduling." (Sandhu and Horton, 1978).

"The results of this experiment suggest that knowledge of leaf and air temperatures, which are relatively easy and inexpensive to determine, can be useful in assessing the water status of corn and sorghum." (Sumayao et al., 1980).

"The results demonstrate the ability of surface temperature measurement by means of infrared thermometry to rapidly assess large areas of cropped land for plant water potential depressions arising from shortages of soil moisture." (Idso et al., 1981)

"We conclude that canopy temperature variability can be used to signal the onset of plant water stress...." (Clawson and Blad, 1981).

"...canopy temperature data can be used to track crop water stress and the effect of stress on yield...soil

factors indicate when plants may be stressed, plant factors indicate when they are stressed. Plant factors, such as water potential, are point measurements that require numerous samples to characterize a field. Canopy temperature measurements can minimize this problem." (Jackson, 1982).

"...linear regression analysis indicate close correlation between water stress index...and water potential..." (Tormann, 1986)

"The Infrared Thermometry device as represented by the "Scheduler" ...is a very sensitive and yet practical means of determining the water stress status of a crop such as vines. The neutron probe while quite accurate in its evaluation of soil moisture content did not provide any measurement of stress...The IRT device is as sensitive to plant stress as the porometer while more simple to operate and maintain than the other devices discussed above...If a known, unstressed vine is used as a reference and the indexes for the vines in question for that date are compared with the reference vine then the IRT method can be used very well for stress management." (Krauter, 1988).

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The Scheduler is based on very sound physical and scientific principles. Those who learn to use it first will be the furthest ahead.

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Points to Remember

- Plant temperatures can be used to indicate plant stress.
- Higher than normal plant temperatures results in yield and quality losses.
- The hotter a plant is (relative to air temperature), the lower its transpiration rate.
- In the field environment, plant temperature variability is a sign that stress has <u>just begun</u>.

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2.4 CWSI Theory

2.4.1 Definition of the Index

Think of the stress index as a percentage. You use percentages all the time. For example, sales commissions are often expressed as a percentage. A salesman wants this percentage to be as high as possible. But, what what kind of stress index reading should you want? Let's compare the index to a sales commission.

$$\text{percent profit} = \frac{[\text{sales commission}]}{[\text{retail price}]} \times 100$$

All your percentages are scaled between 0 and 100 % because you multiply by 100.

similarly,

$$\text{stress index} = \frac{[\text{actual stress}]}{[\text{possible stress}]} \times 10$$

All the stress index percentages are scaled between 0 and 10 because we multiply by 10. Think about it. Do you want high index numbers or low index numbers?

If we can perfectly estimate the actual and possible stress (we can't) then the following chart would be true:

Index		
0	=	no stress detected
1	=	10 % of possible stress
2	=	20 % of possible stress
3	=	30 % of possible stress
4	=	40 % of possible stress
5	=	50 % of possible stress
6	=	60 % of possible stress
7	=	70 % of possible stress
8	=	80 % of possible stress
9	=	90 % of possible stress
10	=	100 % of possible stress

2.4.2 Calculating the Index

At this point, you're probably thinking "O.K., I can understand that much. But how do you measure 'actual stress' and 'possible stress.'" It's not really very complicated. In fact, it's really very easy. You can calculate an index without using a computer, equations or

anything fancy. All you need is some information. What information? All you need to know is:

- air temperature
- relative humidity
- plant temperature

The next step can be done by almost anyone: subtract air temperature from plant temperature. For example, if air temperature is 100° F and plant temperature is 95° F, then 95 - 100 = - 5. The plant canopy is 5 degrees cooler than the air.

Let's do that again, but this time use a simple equation:

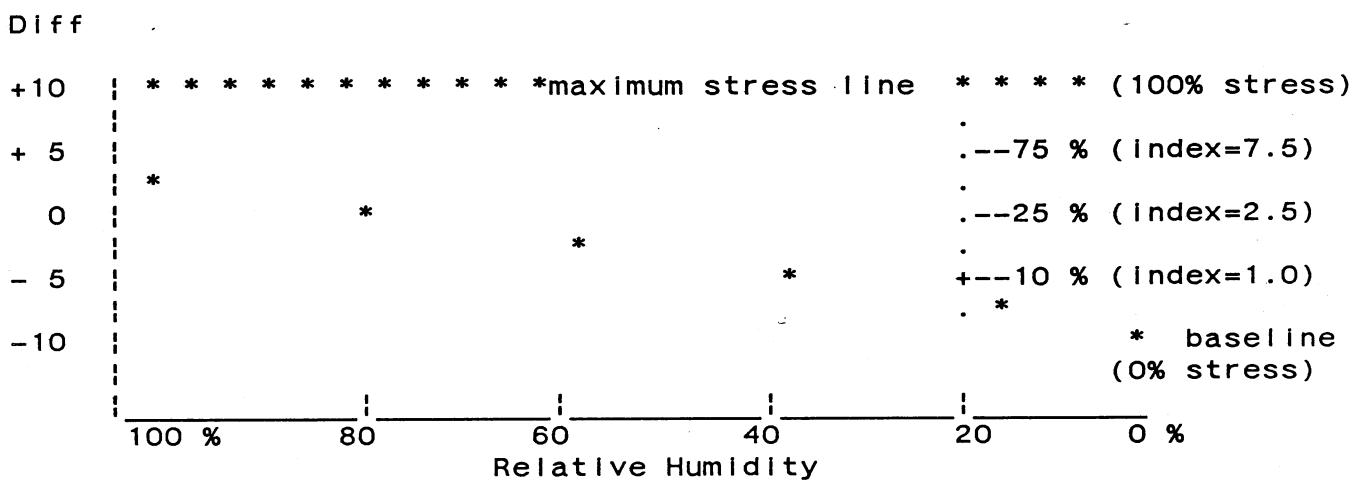
Diff = Tc - Ta	Tc is just the plant temperature (or temperature/air) and Ta is just the air temperature. Let's put the numbers in.
Diff = 95- 100	
Diff = -5	Now we have a name for the number. The name is Diff, which stands for "the difference in temperature between a plant and the air temperature", (or the delta temperature

That's it. The information isn't mysterious. It's very simple. The math isn't hard at all.

Points to Remember

- **The information you need to know to calculate an index is simple. Every one is familiar with air temperature and relative humidity. Plant temperature is the only new piece of information.**
- **The math is very simple**

Now that you know the plants are 5 degrees cooler than the air, and suppose the relative humidity is 20%, just look at a graph like the one below:



This graph is not very complicated. The vertical axis is where we find the value of Diff (remember that subtraction we had to make ?). The horizontal axis is where we look up the relative humidity.

Ready? Let estimate the index for Diff= -5 and Humidity = 20%

First we just look on the vertical axis for the -5 then draw a line from left to right all the way across the graph. Next, look on the horizontal axis and find the 20. Now, draw a line from the 20 to the top of the graph. The two lines you draw will make a + somewhere. The + is where our sample data fits between two other lines.

Now, study the graph. Note that our sample data point is about 10% of the distance between the baseline (0% stress) and the maximum stress line (100% stress). Since our data point has traveled only 10% of the maximum possible distance, we say the index is 1.0.

What would the index be if Diff = + 5 and relative humidity was still 20%? (correct answer is 7.5).

Please note, the horizontal axis in the real index calculation is not strictly determined by the relative humidity but rather a combination of humidity and temperature called the Vapor Pressure Deficit (VPD).

2.4.3 Definition of a Baseline

It wasn't hard to calculate an index was it? All we needed was 3 pieces of information and a simple graph. But

graphs like the one you used in the sample are not found just anywhere. How is a graph like this made?

The index graph has two lines on it. The baseline is the line which shows us what the normal Diff (remember what Diff is?) value is for a healthy crop. The maximum stress line shows us what the highest Diff value is for a very sick (but still alive) crop. The basic process of making this graph is simple.

First, we use the Scheduler on healthy and stressed areas of a particular crop for as much of the season as we can. If we can collect data for more than one season, or in more than one location, so much the better. Two mathematical equations are then developed which effectively summarizes all this information, so that we can use it in a computer. One equation is called a baseline. The other equation is called the maximum stress line. The baseline represents 0% stress (or an index of 0). The maximum stress line represents 100% stress (or an index of 10). If the index was perfect, the index would never be less than 0 or greater than 10. In practice, the index will often be less than 0 and can exceed 10.

Equations have been developed for a number of crops, including:

Alfalfa, almonds, asparagus, barley, cantaloupe, carrots, corn, cotton, cucumber, grapes, green beans, grapes, jojoba, pecans, potatoes, sorghum, soybeans, sugar beets, tomatoes, watermelon, wheat.

Equations cannot be developed for some crops. For example, the leaves of lemons and oranges are thick and waxy. They evaporate water slowly at best. There is no consistent difference in temperature between stressed and non-stressed leaves for these crops. This makes any equation developed unreliable for these type of crops.

It is not essential to have a set of equations developed for a particular crop. General purpose equations called "HIGH" and "LOW" have been developed for use on crops other than those listed above. "HIGH" is used on plants with slow transpiration rates and "LOW" is used on plants which are high consumers of water. These equations will probably not produce a typical 0 to 10 scale. Instead, the customer will need to use them for a while to learn what to expect. But at least he will be able to get started.

2.4.4 Negative Index Values

When we calculate an index, we compare the actual temperature of the crop (measured with an infrared thermometer) with our baseline. If the actual temperature

of the crop is less than our baseline predicts, it means that the crop is cooler than expected. The index will be negative. It is normal to find that measured values of the index are 1 to 2 units below our baseline, i.e., the stress index will be -1 to -2. If the index is more negative than -2, possible explanations are:

- The crop is exceptionally cool, could be wet from rainfall or irrigation or simply using an excessive amount of water. Negative index values are correlated with low pressure chamber readings.

- The sunlight intensity was too low. This can happen quite easily. Mistakes which can cause negative index values include:

  . Clouds in front of the sun. On a cloudy day, the plants are under much less stress than on a sunny day. The manager is concerned about the maximum stress plants exhibit, not the minimum. All measurements must be made with bright sunlight on the plants.

  . Too early or too late in the day. This may not be so obvious, especially if it has been a hot day and the air temperature is still high. The "window of opportunity" is longer during the summer than in the winter. Learn when solar noon occurs in your area. Reference all recommended sampling times to solar noon.

  . There is an error in the baseline. Once we have used a baseline for a while, baseline errors should not be significant. It is not hard to become accustomed to using a baseline that has an error in it. For example, the current tomato baseline consistently reads negative on healthy plants. Irrigation is needed when the index reads about 0 on tomatoes. We could adjust the baseline, but since we have learned how to use the current one, there is no need. In fact, it would confuse current users.

  . You aimed at the shaded part of the canopy. We strongly recommend you keep the sun at your back as a standard practice. This insures you will be looking in the direction of the maximum number of sunlit leaves. This is not necessary on some crops (such as alfalfa) but is always good practice. Make it a rule.

- You aimed too far from the point where you were standing and included the sky in your measurements. This problem is avoided by using proper aiming techniques.

- Air temperature is unusually cool, but the sunlight is bright. In this situation, the crop is also unusually cool, producing a negative index. There is nothing that can be done about this situation. There is also nothing to worry about from a water stress viewpoint. The index is right: the crop is not too hot.

- The sensor gun was too hot. The gun may have been left in a hot truck. If this happens, be sure to allow plenty of time for the instrument to cool off.

Points to Remember

- **Clear skies and time of day are critical considerations.**

- **Negative index values are normal.**

- **Negative index values indicate no stress.**

- **Mistakes can artificially create negative index values.**

2.4.5 Positive Index Values

The agronomic interpretation of positive index values may be different for each crop. For example, cantaloupes is a crop on which you want only small positive index values (0-1). Cotton can tolerate moderately positive index values (2-3) without any damage. Seed alfalfa requires large positive values (7-9) to produce seed. For this reason, we have written a series of KNOW-HOW bulletins to explain what we currently know about interpreting index values for a particular crop. These bulletins are revised as new information becomes available.

Positive index values occur for two reasons:

1. Because the crop is hotter than the baseline predicts.

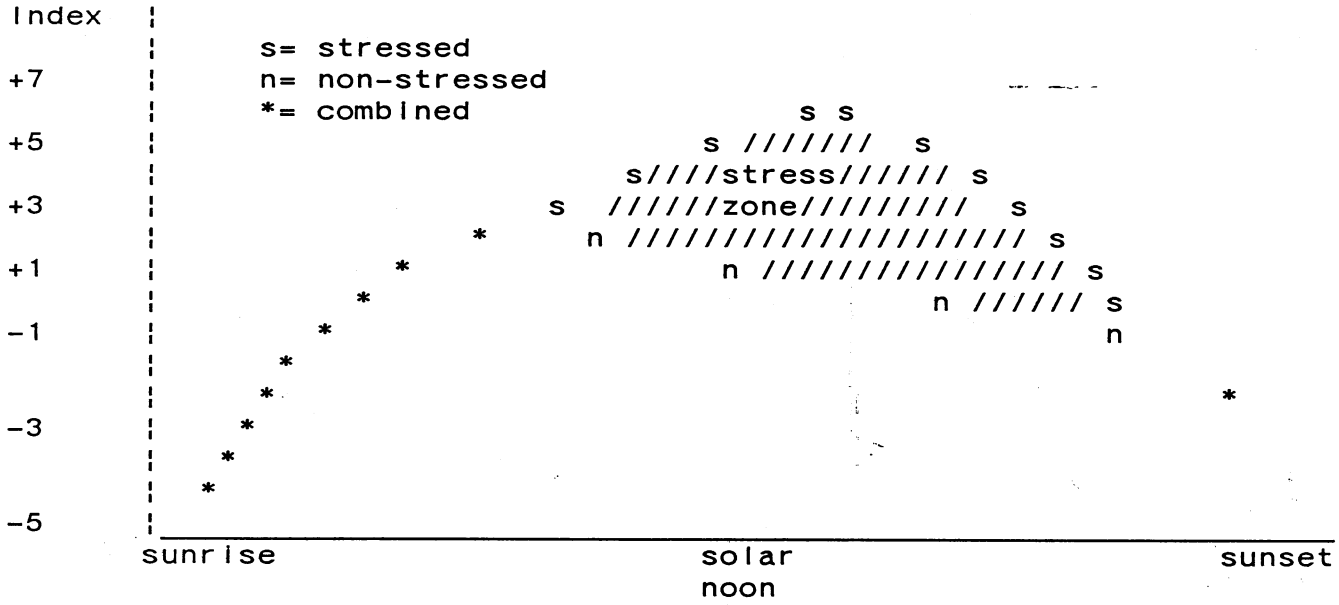
2. The sensor gun is cold. If the gun is stored in a cool room and then taken outside on a hot day, the index values will be too high for the first few minutes.

The index can be greater than 10. There are two reasons why. First, bare soil can influence the index. If you aim so that some soil is measured, the index could exceed 10. Second, we are purposely conservative in how we estimate the maximum stress line. This allows us to give greater sensitivity to the index. Severely stressed crops may exceed 10.

2.4.6 Index Trends

Hourly Trends

The index is not constant from hour to hour. It varies with the sun. The graph below shows the expected hourly pattern for a stressed and non-stressed crop.



You should already know about sunrise and sunset, but what in the world is "solar noon?" In the Old West, another name for solar noon was "High Noon." Solar noon occurs when the sun is exactly half-way between sunrise and sunset. The sun is brightest and hottest at this time. Solar noon can occur anywhere between 12:00 p.m. and 2:00 p.m., depending on where you live and whether or not you are on daylight savings time or standard time. The easiest way to determine solar noon is to use the old Boy Scout trick of placing a stick in the ground. When the shadow of the stick points directly south, it is solar noon.

You can see from this graph that you have a relatively limited "window of opportunity" to make your stress readings. As stress becomes more and more severe, this window becomes wider. Crop managers are usually interested

in avoiding severe stress. When stress is first indicated during this mid-day period, the crop is basically non-stressed the rest of the day. By operating near this mid-day peak, you are using the Scheduler at its best.

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Points to Remember

Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour.

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Daily Index Patterns

The pattern of the index between sampling dates is VERY important.

The first thing you need to know is "what's normal for this crop?"

The second thing you need to know is "how does this field compare with "normal?"

YOU MUST UNDERSTAND THE BIG PICTURE IN ORDER TO UNDERSTAND INDEX READINGS. The index for every crop has a normal pattern. For example, a row crop, such as cotton, would have a seasonal pattern like the one on the next page. The dotted lines represent the upper and lower limits to normal readings. If an index value is above the upper line, the crop is under stress. If an index value is between the lines, it means the crop is not under stress.

Reasons the index can be above normal:

- Crop is under stress
- Sensor gun is too cold

Reasons the index can be below normal:

- Crop is wet
- Wrong time of day
- Poor aiming technique
- Unusually cool air
- Sensor gun was too hot

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Points to Remember

You must know the BIG PICTURE for a crop to know what is normal.

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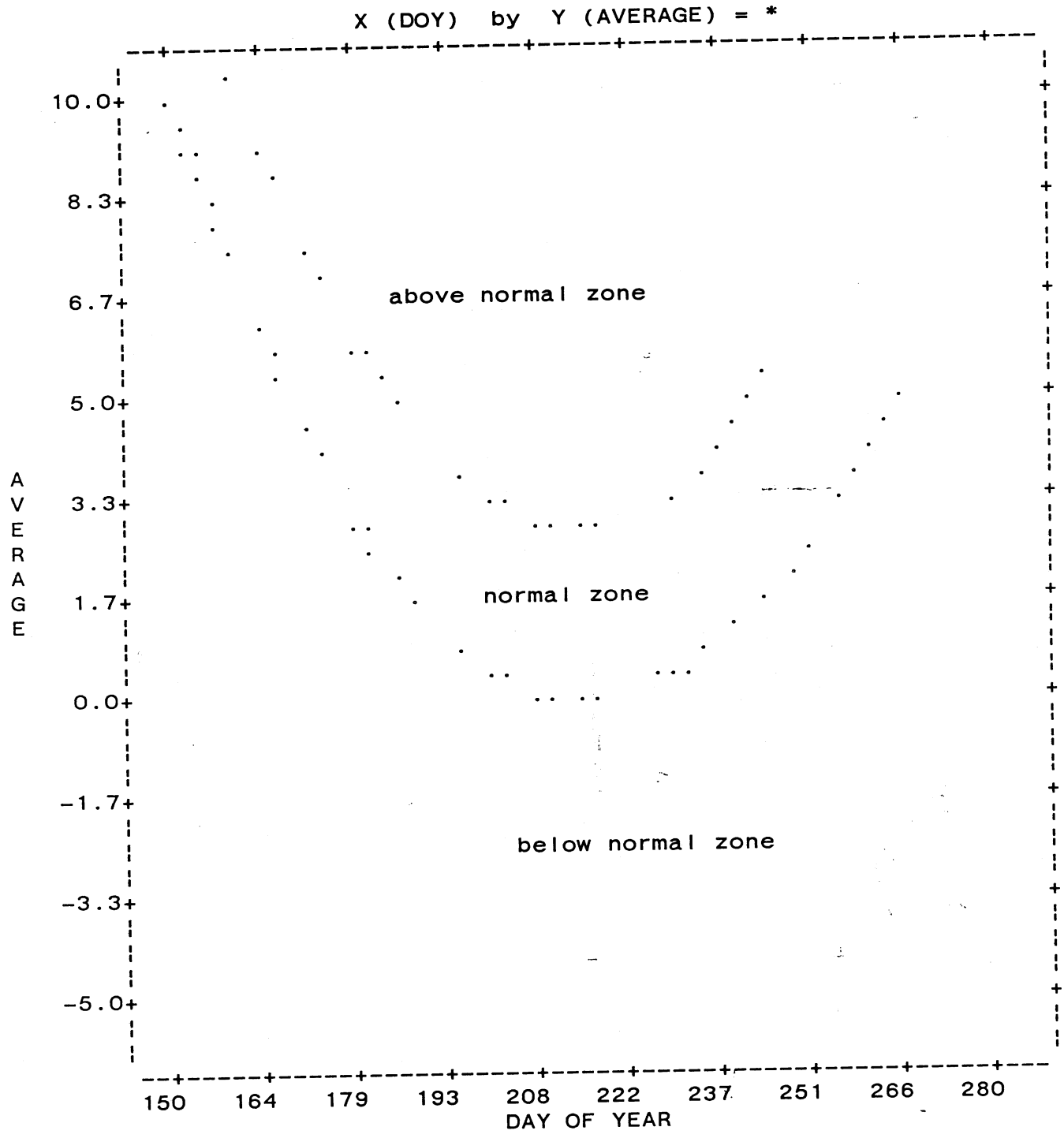
X (DOY) by Y (AVERAGE) = *
10.0+
8.3+
6.7+
5.0+
3.3+
1.7+
0.0+
-1.7+
-3.3+
-5.0+
AVERAGE
above normal zone
normal zone
below normal zone
150
164
179
193
208
222
237
251
266
280
DAY OF YEAR

Oops. There's a new term on the horizontal axis: "DAY OF YEAR". What's that? All we do is give every day in the year a number (there are 365 days in the year). So, January 1 is DAY 1, January 2 is DAY 2 etc. This table might help you understand:

Month	Days of Year
January	1-31
February	32-59
March	60-90
April	91-120
May	121-151
June	152-181
July	182-212
August	213-243
September	244-273
October	274-304
November	305-334
December	335-365

It's a little tougher to find a date on a graph using DAY OF YEAR values, but it's a whole lot easier to graph the information on a computer.

****

The normal management objective on most crops is to either have the index decrease with time, or be stable with time. An index is "stable" with time, if it stays within a zone about 3 index units wide. For example, readings would be considered stable if they remained between -2 and 0 or if they remained between 1 and 3. Many users can maintain a zone of stability with smaller limits than these, especially users who have drip irrigation systems. When you are analyzing index patterns, the key is the trend (increasing, decreasing, or staying flat).

****

2.4.7 Factors Which Affect Index Values

Anyone who is experienced with plants knows that many cultural practices affect plants. Anything that affects a plant has the potential to affect the index. Factors which are known to influence index values include:

- Variety. With some crops, such as corn, varietal differences appear to be small. Some crops, such as grapes, appear to have significant varietal differences caused primarily by leaf size differences. The spread in index readings may be up to 2 index units. This does not mean that you need a separate baseline for each variety. It does mean that a user will probably have to use the Scheduler for a season on a particular variety before he will know what to expect for normal index readings.

- Wind. Studies indicate that wind speed fluctuations can cause a variation in plant temperature of 2 to 4 degrees F. This means that CWSI can be expected to fluctuate up to about 2 stress units as the wind speed varies. The key to obtaining accurate index numbers is sampling technique. Remember, plant temperature (and CWSI) are both fluctuating around a fairly stable average. Effective sampling technique will produce a good estimate of that average.

- Time of day. Plant temperatures are controlled by the sun. The sun changes in brightness (and its heating power) throughout the day. The sun is usually brightest and hottest at "high noon", or when the sun is directly south. There is only a small difference in the brightness or heating power of the sun plus or minus 1 hour of solar noon. Because the maximum air temperature for the day usually occurs after solar noon, the best time to sample is about 1 hour after solar noon. More about solar noon in the next section.

- Clouds. Clouds protect plants from the sun. You feel cooler when you step from the sun into the shade. Plants are cooler when the sun is behind a cloud. The index value which is of most value to a grower is the index value obtained when the sun is shining brightly. The index value will always be lower when the sun is behind a cloud than it is when the sun is shining.

****
The Scheduler is not a voltmeter which provides exactly the same answer every time you turn it on. The basic reason for this is that an agricultural crop is dynamic. It responds to a constantly changing environment. The guidelines we provide will be useful to initially judge the meaning of Scheduler data, but some user adjustments are inevitable.
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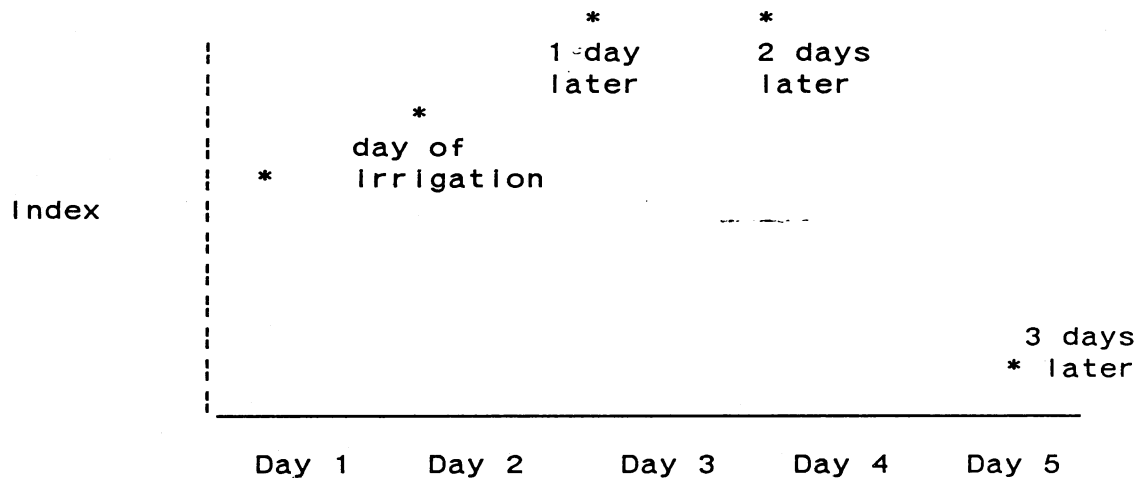
- Soil. Hot, dry soil will influence index readings. Remember, bare soil also has a temperature and an index value. Below are some index values for bare soil at various soil temperatures (assume air temperature is 90° F and relative humidity is 30%. The index values given are for cotton):

Soil Temperature	Index Reading
80	-1.0
90	6.1
100	13.3
110	20.5
120	27.6
130	34.8
140	42.0
150	49.2

You can see that soil temperatures may have no impact at all on index readings or the impact can be extremely strong. The hotter the soil temperature, the greater the impact. You must be careful to avoid soil in your readings.

- Too much water. Over-irrigation can affect the index (it affects plants also). The reason is simple: plants need water and air in the soil in order to function properly. It would not be unusual to see the following:



WHAT'S GOING ON? Isn't an irrigation suppose to make stress go away? In theory, yes, but in reality, some irrigations (for a few days) create stress. The reason is simple: heavy irrigations force the oxygen out of the soil. Without oxygen, plant roots are unable to use soil water. So, if you run out to the field the day after an irrigation, don't be suprised if you see the stress levels increase instead of decrease.

2.4.8 Relating the Index to Other Measurements

Yes, there is more than one way to measure plant stress. One request which we constantly hear goes something like this "Well, what is the relationship between the stress index and whatever it is that the customer is currently using?" The idea is that it would be very nice if we could make an index reading and tell the customer "This reading is equal to XXX soil moisture, or XXX tension, or XXX pressure potential, etc."

Yes, that would be very nice. But it's not going to happen. Think about it this way. Let's suppose we want to develop a relationship between these two things: a) the type of house a person lives in and b) the income level a person has.

It takes no great stretch of the imagination to realize that these two things are strongly related. We could say, with a great deal of confidence, "In general, the more expensive the house a person lives in, the higher their income level". Right? This is just like saying "In general there is a relationship between the stress index and soil moisture, soil tension, and pressure potential.

In general. But now, an FBI agent comes to you and says "I want you to tell me the income level of Mr. X. Go take a look at his house, then return and tell me how much money he makes." Guess what! You couldn't do it. Despite the fact that you know "In general" the type of house a man lives in reflects his income, there is no way to predict this for a specific individual. There are simply too many other unknowns. For example, does his wife work or does he have a rich uncle, or is he deep in debt, etc.

This principle holds true for comparing stress index readings with other readings. There is, in general, a strong relationship between index readings and other measurements. But too many unknowns exist to develop a 1:1 relationship. The index measures the stress level. Other techniques were designed to measure other things. If you want to know plant water potential, then measure it with a pressure chamber. If you want to know the stress level, then measure it with a Scheduler.

A good manager wants to know many things about his crop. It is a well understood fact that yields are very strongly linked to the amount of nitrogen in the soil. Every good manager keeps track of how much soil nitrogen he has. But, if that manager was asked "What yields do you expect based on your soil nitrogen levels?" Could he answer the question ? Of course not. Soil nitrogen is critical, but so are many other things. So, he monitors nitrogen, knowing that he has to keep the nitrogen level within certain limits. But, he also monitors potassium, phosphorous, and many other things. Monitoring the stress index is much like monitoring nitrogen levels. It's not the only piece of information a manager needs but, there is no doubt that the index should remain within certain limits in order to achieve maximum productivity.

2.5 INSTRUMENTS FOR MEASURING STRESS

2.5.1 Reasons for Needing Instruments

Growers have been producing crops for many years without using technical instruments to help them make decisions. So why should they start? After all, most growers know they can produce X tons per acre by making all their decisions "by the seat of the pants" or "experience." But, the truth is that plants have the potential to produce more than most growers achieve. A grower must have a desire to solve a problem before he will recognize the need to start using an instrument such as the Scheduler. Problems include:

- Large acreages. They have a need to obtain information rapidly about many different sections of their operation. The Scheduler was designed specifically to obtain information rapidly. Current grower techniques are often based on small samples of a few plants or localized soil samples.

- Manpower. They may have an insufficient number of trained people to help. They need inexpensive assistance in obtaining quality information about the current condition of their crop. When you look at the number of acres that one person can monitor with a Scheduler, the cost of the unit is very small on a per acre basis.

- Uniformity. Some sections of the farm may be in super condition, and other sections may have some real problems. Ultimately, this costs the grower money. Many problems are induced by the grower because growers do not have the information they need to discriminate differences in crop condition between areas until visual symptoms occur, at which point yields are often already damaged. The Scheduler allows a grower to manage sections so that stress levels remain as uniform as possible.

- Confidence in current techniques. Many of the current techniques growers are using are not very satisfactory. There is often a desire for something better. We believe the Scheduler is better than other devices growers use.

- Documentation. Growers like to see "the season at a glance." To do this with current techniques requires a great deal of effort in learning to understand computers, in developing software, and in entering data into a computer. The Scheduler provides a grower with two very useful forms of documentation.

2.5.2 The Plant is the Key

The ideal moisture stress reading is based on a direct plant measurement instead of a soil or atmospheric measurement (Clark, 1973). Think about this. Agriculture is concerned primarily with growing plants. Does it make sense to ignore information which comes directly from the plant? Of course not. It is important to understand that the plant is the best guide to its condition. Suppose you went to the doctor because you were feeling bad. Then, the doctor phones up the National Weather Bureau to find out the weather forecast. He then says, "Yup, I think you're probably going stay sick for about 3 or 4 more days." There's no doubt the weather is an important factor in making people sick, but wouldn't feel just a little more confident in the doctor's diagnosis if he said "stick out your tongue and say AAAAH". Why should agricultural "experts" believe that they can ignore direct plant measurements and still achieve maximum productivity (and profit)? It doesn't make sense. The main reason farms exist is to produce plants and plant products. Plant condition is affected by the total environment of the plant. A manager has two choices:

- Measure the environment (soil, weather) and guess the condition of the plant.

- Directly measure plant condition.

Why make guesses when its just as easy (easier?) to make direct measurements?

2.5.3 Instrument Requirements

PLANT TEMPERATURE IS THE KEY TO PLANT CONDITION.

Instruments designed to measure water stress should:

1. Measure canopy temperature accurately. Plant temperature is the key to understanding plant behavior. Everything that a plant does is controlled by the temperature of the plant. While we do not understand everything there is about plant temperatures, we do understand that plant Temperatues can be "below normal", "normal" and "above normal." It only makes sense that plant temperature measurements be as accurate as possible.

2. Be portable. this would allow measurements to be made anywhere that is desired. The instrument must not weigh too much or be too clumsy to use.

3. Be rugged and sturdy for use in the field. Any piece of equipment used in the field is exposed to jarring, bouncing, hot and cold temperatures, and dust (among other things). Many "laboratory quality" instruments would be destroyed by the way farmers would handle them. If it isn't rugged, don't use it in the field.

4. Allow for multiple readings in the field (Lange, 1965). The reason is simple : fields are variable. One section may have a heavy soil, another section may have salt problems. One sample of one plant is a poor representation of the overall average. It must be possible to sample many plants in order to have confidence that the reading represents the true average.

5. Be simple to use. No matter how good it is, if it isn't simple to use, most growers will not use it.

6. Correlate well with physiological measurements. (Kramer, 1963). Instrument readings must make sense. The instrument must be designed to provide information which relates directly to the condition of the plant. This means the scientific basis for the instrument must be strong. The Scheduler design fulfills these requirements.

2.5.4 Scheduler^{R} Hardware Features

- Aspirated air temperature and humidity sensors.

- Infrared thermometer

  Distance: one inch to infinity
  Range: $\pm$ 108^{o}F from ambient
  Field of view: 8^{o}
  Spectral response: 8-14 um
  Accuracy: $\pm$ 1.0^{o}F
  Repeatability: $\pm$ 0.4^{o}C
  Emissivity: 0.99
  Operating distance: 1 inch to infinity

- Ambient temperature

  Range: 32^{o}F to 140^{o}F
  Accuracy: $\pm$ 1.0^{o}F
  Resolution: 0.2^{o}F

- Humidity

  Range: 0 to 100%
  Accuracy: $\pm$ 5%

- Solar Radiation:

  Range: 0 to 100 mW/cm^{2}
  Accuracy: $\pm$ 10%

- Response Time:

  Screen update < 2.0 seconds
  Sample frequency < 0.5 seconds

- Microprocessor: 64-K -- 8 bit.

- Display: 2-1/2 X 1-1/2 LCD on processor

  1-1/2 X 1 inch on sensor gun

- Serial Interface:

  RS-232 25 pin male connection
  Baud Rates: 50-2400 (selectable)
  Character Sizes: 5-8 (selectable)
  Other download parameters also selectable

- Softside carry case.

- Warranty: 1 year

- Power -- 6 C cell batteries, with an expected life of 20 operating hours.

- Recharging port provided for use with rechargeable batteries.

CHAPTER 4 - SAMPLING TECHNIQUES

4.1 Guidelines

The major concerns in sampling are :

1. **Operating a clean unit.** Use in dusty conditions requires clean the cleaning of the lens of the infrared thermometer. When the lens becomes dirty, the temperature readings are lower than they should be. This results in index readings lower than they should be. The instruction manual will give you complete instructions.

2. **Adjusting to ambient conditions.** If the sensor gun is stored in a cold office, or a hot truck, the air temperature reading may not be accurate, even after the 94 second cound-down. Some common sense must be applied to allowing the gun to adjust to the outside. This is very important in the first 10-15 minutes of operation.

   One technique used to insure the gun has adjusted is to stand in one spot and take multiple samples. When you obtain index averages, from 3 separate samples, that are within 0.5 stress units, the gun is adjusted.

3. **Time of day.** The user should be consistent with time of day. He should return to measure the same field at about the same time each day.

4. **Proper aiming technique.** The steps to aiming properly are:

   a. Keep the sun at your back.

   b. Keep the gun 3 feet above the soil. When soil is hot and dry, it heats the air near the surface and affects the index readings.

   c. Select a target that avoids soil, sky, shadows, wood, or anything that is not green, sunlit vegetation.

      - Aim at individual leaves.

      - Aim down the row (refer to the chart on spot size to make sure you don't aim too far down the row, especially when bare soil is between the rows).

- Make your own sampling surface if necessary. On small leafed crops, for example pecans, it may be necessary to "bunch" leaves to create a surface of sunlit leaves to sample.

d. Aim at the crop at least 2 seconds before squeezing the trigger. This insures that you do not accidentally enter erroneous data.

e. Do not aim more than about 30 feet from the point you are standing. Remember, when you aim at a target 30 feet away, you are really seeing a target that is about 4 feet wide and 270 feet long.

5. Sampling spot. One of the keys to interpreting the stress index readings is the trend of the index (is it increasing or decreasing with time?). This makes it important for a user to sample the same spot on different days.

6. Has the user selected spots which make sense in terms of his irrigation system? With an effective sampling scheme, there will be sufficient time to collect data on most farms.

7. How does the user treat the instrument between fields? After he samples one area, and is traveling to the next, what happens to the sensor gun? The "nose" of the gun should NOT be placed back in the holster. A good travel technique during a sample session is to place the gun upside down in the holster. The fan SHOULD remain on at all times. This is not the time to worry about battery life. Your concern at this point is accuracy. Air conditioning (for 5-10 minutes) should not affect the accuracy of the sensor head.

8. How much abuse is the sensor gun, especially the coiled cord, receiving? Cord failures can occur in units in which the cord is twisted, knotted and yanked on. Symptoms of a broken cord are:

- Software locks up (caution, the software can lock up in the R&D models if one of the computer parameters is accidentlly changed. Check to make sure XON/XOFF is DISABLED.

- Sensor readings become wild (canopy temperature of 300 degrees or relative humidity of -1000% , etc.)

9. Do not take an excessive number of data points in one spot. In spite of its great number collecting ability, all you need is about 10-15 shots per location.

10. Stable sunlight. The sunlight sensor on the

Scheduler is designed for relative readings. The highest reading you obtain on one unit may be an 85 while a different unit may read 95. The reason for the measurement is to allow a user to decide:

- Was the reading near maximum (it should be), indicating a clear day and sufficiently strong sunlight?

- Were the readings stable? When you examine a print-out, the solar readings should be within about 10-15 units of each other. If the spread is greater than this, it may indicate the data was taken under partly cloudy skies, too early or late in the day, or the user was simply casting shade on the back of the gun with his body. You should ignore the solar readings when:

- You are sampling trees, the solar sensor was designed assuming the "nose" of the gun was pointed slightly down.

- Winter-time. The Scheduler is not used by many during the winter months. The sunlight sensor is inconsistent when the sun is at winter-time elevations. The other sensors are not affected.

4.2 Time of day

If you have 1 hours worth of data to take, the best time to start would be 90 minutes after solar noon. Try to arrange the customers sampling so that all samples can be taken in 1 hour. It's surprising how much acreage can be sampled in an hour once the irrigation scheme on a farm is understood.

If you have 2 hours worth of data to take, then start 30 minutes after solar noon. The index may change some during this time, but should not be a serious concern.

If you have 3 hours worth of data to take, then start 30 minutes before solar noon. There may be a noticeable change in the index between the first and last samples, depending on how much the air temperature changes.

If a user absolutely feels that he cannot make readings between solar noon and the two hours afterward, then he must be reminded to :

- Be consistent. Always sample the same area at the same time of day.

- Do not compare index values taken at 11:00 with index values taken at 2:00. They will probably be different. Refer to figure 1 to see the normal daily index pattern.

In some areas, clouds may develop in the afternoon. This means that the environment becomes more moderate. The best time to start sampling in such areas is about 1 hour before clouds usually start developing.

CHAPTER 5

INTRODUCTION TO THE CROPLINK

The Croplink is a combination of a weather station for the determination of evapotranspiration in the field and an infrared sensor to measure Crop Water Stress Index. The reason for this combination is that it solves a major problem of data collection for water management. There are two basic types of traditional measurement techniques used for irrigation scheduling:

1. Devices that collect a large number of readings from many points in the field so that the average conditions in that field for that particular instant can be determined. The pressure chamber, porometer and manual soil probing are examples of this technique.
2. Devices that collect a series of readings from one point in the field which is designated an index and assumed to be representative of the rest of the field. Examples of these are tensiometers, resistance blocks and the neutron probe.

Each of these basic techniques has a serious problem. The methods that collect readings from many points within a short time like the pressure chamber may accurately sample the field but for only the period when the device is in use. There is no certainty that the time period selected is the correct one. If the readings are taken at noon they might show no stress but three hours later the crop may be in serious stress. Weather conditions affect the Et rate which in turn affects the stress level of the crop. If the readings are taken on an

especially hot, dry day an irrigation may be indicated. If the following day starts a week of average or cooler weather, the plants may well be unstressed for the period of the lower Et rates.

The devices that measure conditions at an index point can show the daily changes if they are read frequently but there is the problem of assuming that the conditions at the sampling point are truly representative of the field. Consider the fact that a tensiometer samples a volume of soil about the size of a golf ball. That is about 2 ounces of soil. The root zone of a 20 acre vineyard weighs about 300 million pounds. A few ounces here and there may or may not be characteristic of the rest of the field but the long odds should at least make one think about it.

The Croplink is able to improve on both of the above techniques. It samples frequently and automatically logs the collected data so that the change in field conditions over time can be easily monitored. The Infrared sensor is a remote sensing device that can be used to average the conditions over a large number of crop plants so inconsistencies at any one point can be averaged. The collection of weather data for Et calculations is also less subject to spatial variability than other factors that are measured for water management purposes. The soil characteristics, uniformity of water application and even crop growth will vary more than the microclimate conditions in a field. The weather conditions may change significantly over time but the Croplink's 3.6 minute data collection interval takes care of that.

The combination of an estimated irrigation schedule from a water budget and confirmation of the prediction of water stress by the CWSI technique as discussed in Chapter 9 is one of the best methods for commercial irrigation scheduling. Presently, the grower or consultant must either have an expensive, dedicated weather station or use a service such as the California Irrigation Management Information System which provides a network of stations in major agricultural areas. The irrigation manager must then collect CWSI data with hand held equipment to correlate with the water budget schedule. This is an entirely workable procedure but there are some ways in which the use of Croplink technology can improve on it.

The weather conditions that are used to calculate the Et are reasonably consistent but in California data is most often collected by CIMIS where the weather station can be 20 or more miles away. This may be close enough but factors such as wind speed and cloud cover can be quite different over a distance of 20 miles. Additionally, the station and associated computer system is maintained by a state agency. While this may be an excellent example of our tax money at work, it also means the user has little control over the reliability and accuracy of the system. The alternative is a dedicated weather station at the farm site but until the advent of the Croplink, these have been expensive and required considerable technical ability. The great advantage in this regard, of the Croplink is the fact that the data logging system is just a standard PC type computer that can stay in the office. Most of the problems with previous weather stations have been with the system to store and transfer the information collected by the weather

sensors. The Croplink seems to solve most of those difficulties. The fact that there is also a leaf temperature measurement taken at the same time as the weather data means the same system can calculate a CWSI for each 3.6 minute period. It is also a convenience to have the data collected directly into the computer that can be used to calculate the Et and generate the irrigation schedule.

The Croplink is potentially very useful for not only commercial water management but also experimentation. The techniques for use of the hand held Scheduler in the field require calibration for the particular crop. This crop data along with the determination of limitations of time and other conditions requires the collection of a great deal of data. The use of the Croplink for this calibration process will result in better information with less time and labor than the methods previously used.

CHAPTER 7 - DATA ANALYSIS

7.1 What Is Data Analysis?

In the most unscientific sence, it is the scheme for evaluating the results of field sampling.

7.2 Data Quality Control

Is the crop temperature data acceptable?

One key to deciding if crop temperature data is acceptable is to examing the STD, or standard deviation value. STD is a measure of how uniform the canopy temperature samples were. Some variability is expected, and some can be caused by stress, but STD should be within normal limits (2-4^{o} F). We have found that even researchers who have 2-3 years experience with the Scheduler periodically store samples which have STD values which are unacceptable.

It is more difficult to answer this question in the PRODUCTION models, since there is no room in the software for calculating STD. One indication of improper sampling will be a canopy temperature average that is very different from the others. You must be careful about using differences in averages, however, since this is exactly what you are looking for.

Is the air temperature data acceptable?

This can be decided by looking at a graph of air temperature versus time. If the user has a clear pattern in his air temperature data (increasing or decreasing with time) it probably indicates the sensor gun was either too hot or too cool. Patterns in the air temprature data can invalidate part or all of a data set.

Were effective sampling techniques used?

This is a judgment call. Chapter 4 should be studied and thoroughly understood. If you are confident in the sampling, and the data do not indicate a problem, then proceed.

7.3 Key Facts to Remember

The following facts apply to the leaves of most crops. Keep these facts in mind as you respond to individual questions from customers.

- Young leaves are cooler than old leaves in some crops and warmer than old leaves in other crops.

- Individual leaf temperatures constantly fluctuate around an average value.

- Leaves can wilt when stressed or non-stressed. Plants that are wilted, but have adequate soil moisture, will be cooler than wilted plants that are moisture stressed.

- Stressed leaves can be up to 20° F hotter than non-stressed leaves.

- Non-stressed leaves are generally cooler than ambient in most crops.

- Stressed leaves are generally above air temperature.

- Measureable increases in leaf temperature occur 1 or more days before visible wilting occurs.

- Differences in temperature between stressed and non-stressed plants are directly correlated with differences in their transpiration rates.

- Plants growing in saline soil may be much hotter than plants growing in non-saline soil.

- Leaf temperatures of different varieties may differ by 2-4 F under the same soil moisture conditions.

- Differences in yields are associated with differences in leaf temperatures.

7.5 CASE STUDY: COTTON--1988

Source of Data:

West Side Field Station
Commercial Cotton Farm, Lemoore, California

7.5.1 Comparison Between Users

Standard Deviation of Crop Temperature

There was a significant difference in the standard deviation (std) of crop temperatures recorded at the West Side Field station and the commercial site Fig 1 and 2). Std values never exceeded 2.2° F at the commercial operation, but were frequently as high as 4.4° F at the West Side site (but the majority of std values were still below 2.2). On a

few occaisions, extremely high std values were recorded at the West Side location. These results reflect one of the serious concerns about Scheduler users: How consistently are they really using the instrument? (I'm sure both users believed they were being consistent, but it's obvious that one was actually more consistent than the other).

This is probably a reflection of the fact that the experiment at the West side station was exceedingly large and complex, thus creating a large opportunity for variation. Over 1200 separate samples were taken at the West Side station. Only 9-18 had std values that seemed to be caused by operator error (about 1%). Yet, a user who experiences only 1% "strange" values may come to believe that the Scheduler has a problem. If you suspect a user is creating some of his own variability problems, it would be smart to let him collect data with an R&D model for a while (if he doesn't already own one) and check the consistency of his STD values. Standard Deviation of Pressure Chamber readings.

No statistics are available on the standard deviation of the pressure chamber readings at any location. This illustrates one difficulty in comparing the Scheduler with the pressure chamber. The Scheduler is capable of collecting and storing its data from multiple sites, making it very easy for a grower to become aware of the true nature of the index behavior. Time and energy constraints make it very difficult to collect more than a few pressure chamber readings per field.

Sample Size

The majority of Scheduler data points were comprised of the average of between 10 and 40 separate samples (Fig 3 and 4). Pressure chamber readings comprised the average of 3 separate leaves.

Figure 1. Standard deviation of crop temperatures at a commercial cotton site near Lemoore, Calif, 1988.

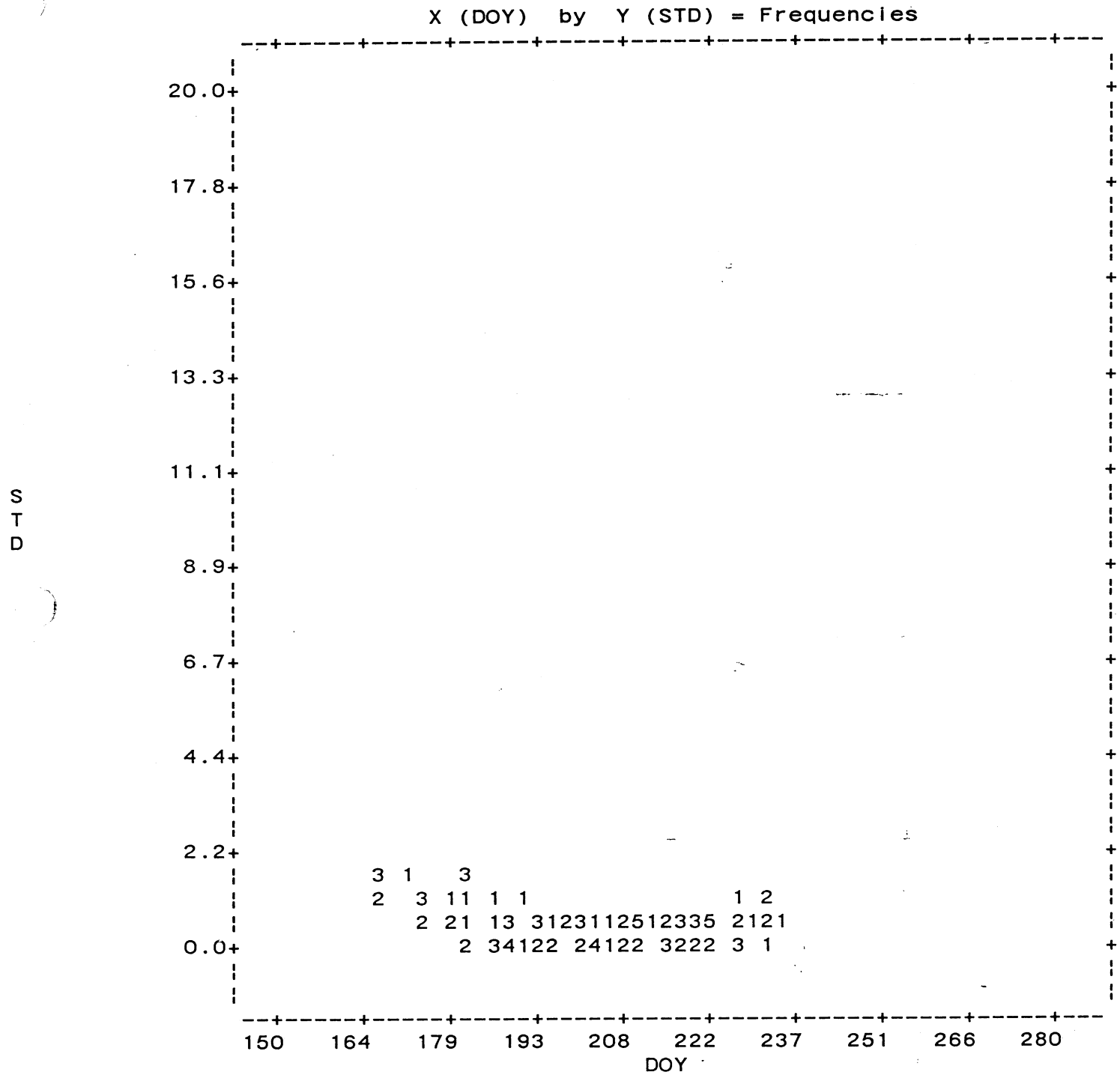


Figure 2. Standard deviation of crop temperatures at the West Side Field station.

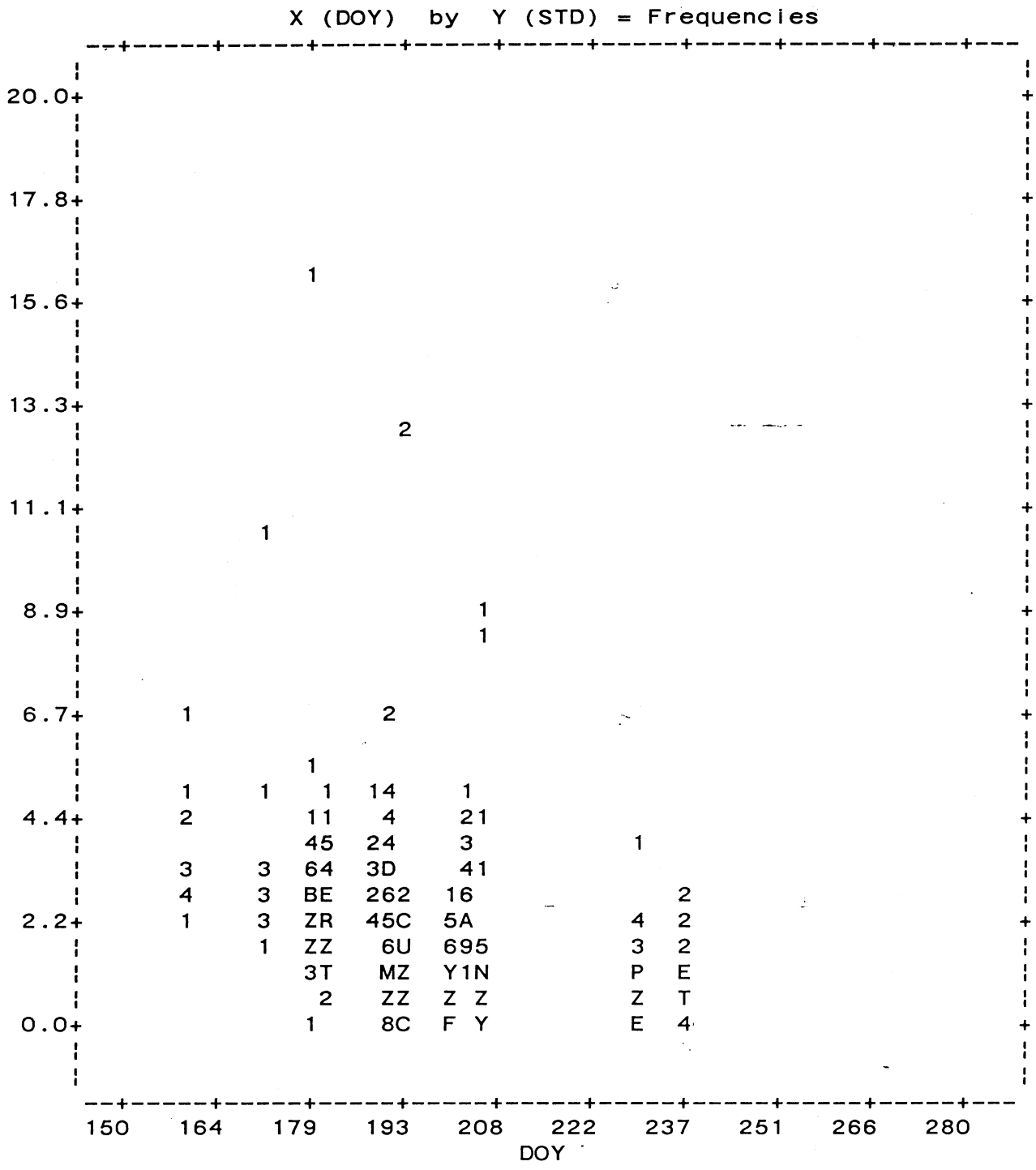


Figure 3. Number of samples taken per observation for the Scheduler at the commercial cotton site.

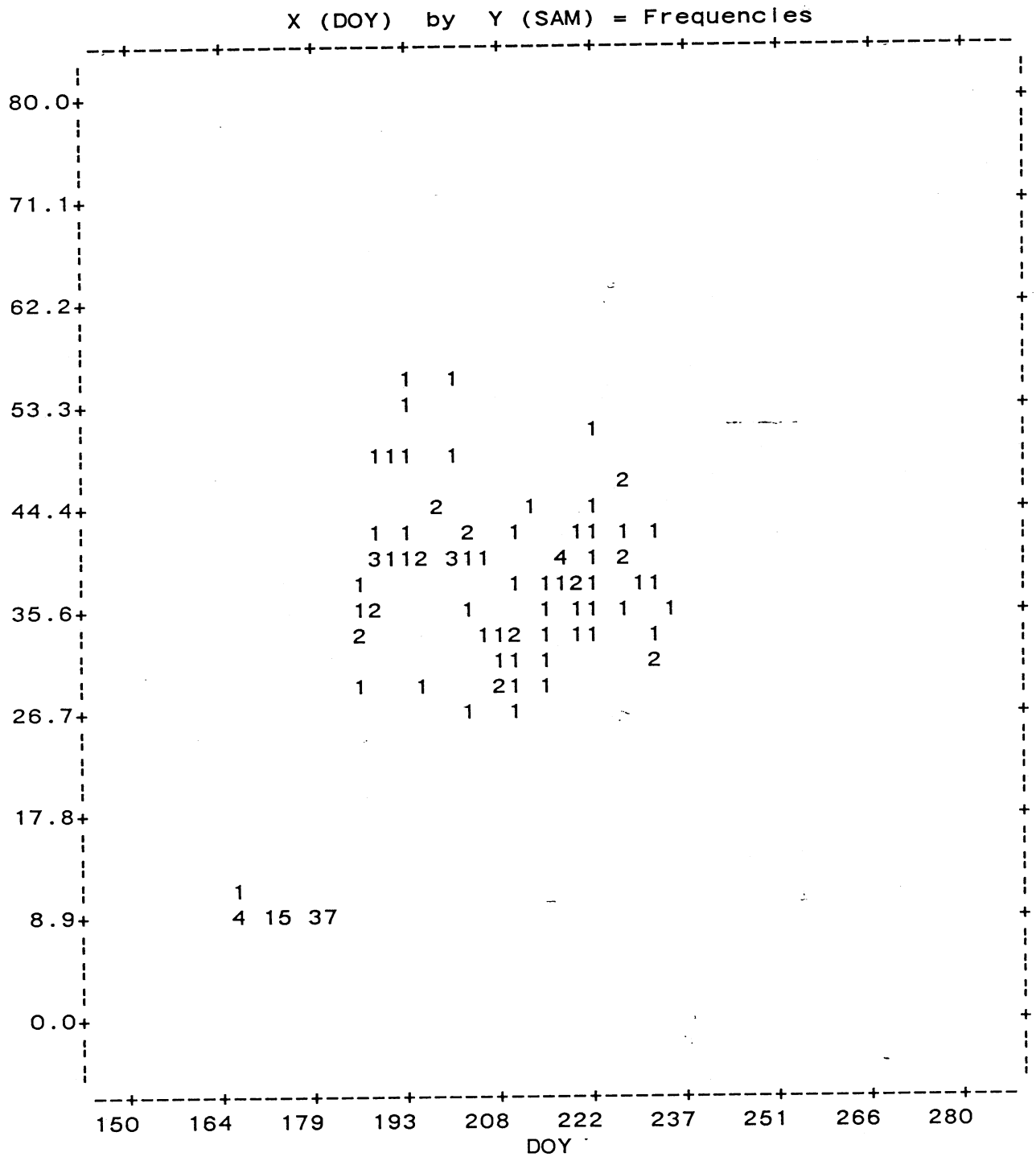
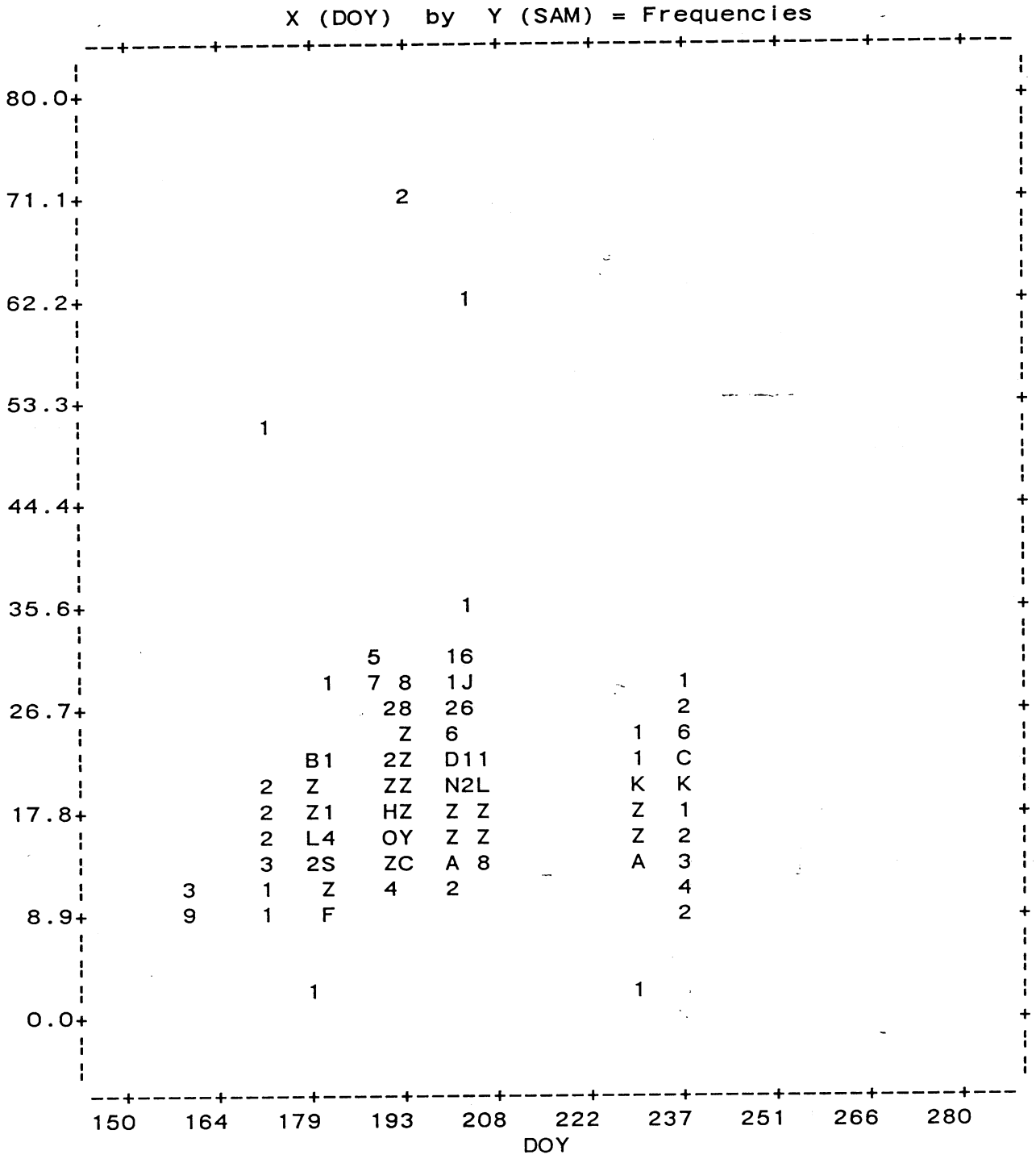


Figure 4. Number of samples taken per observation with the Scheduler at the West Side location.



7.5.2 Index and Pressure Chamber Comparison

The Scheduler stress index and the pressure chamber readings followed similar daily patterns (Fig 5-8) especially after July 1 (DOY=182). Prior to that time, there was an inverse relationship between the two sets of readings. It is clear from these data that a) pressure chamber and Scheduler readings are systematically related to each other and b) the relationship between the two sets of readings is non-linear, making it unlikely that one reading can be used to exactly predict the other. This is confirmed by Fig 9.

7.5.3 Irrigation scheduling with the index

Figure 8 provides a good framework for discussing how to use Scheduler index readings in relation to previous work conducted using the pressure chamber. Figure 8 represents the average daily behavior of pressure chamber and index readings on well-irrigated cotton for 1988. In 1989, a grower would compare his index readings with the average reading for that same time of year in 1988. He would allow a buffer zone of about 3 index points to account for the normal scatter that occurs in using the Scheduler (scatter caused by windspeed, and time of day for example). If his readings still exceed the buffer zone, then irrigation is required. Figure 8 can be generalized by substituting a phenological scale for calendar time.

Figure 5. Patterns of index and pressure chamber data for the West Side location, 1988.

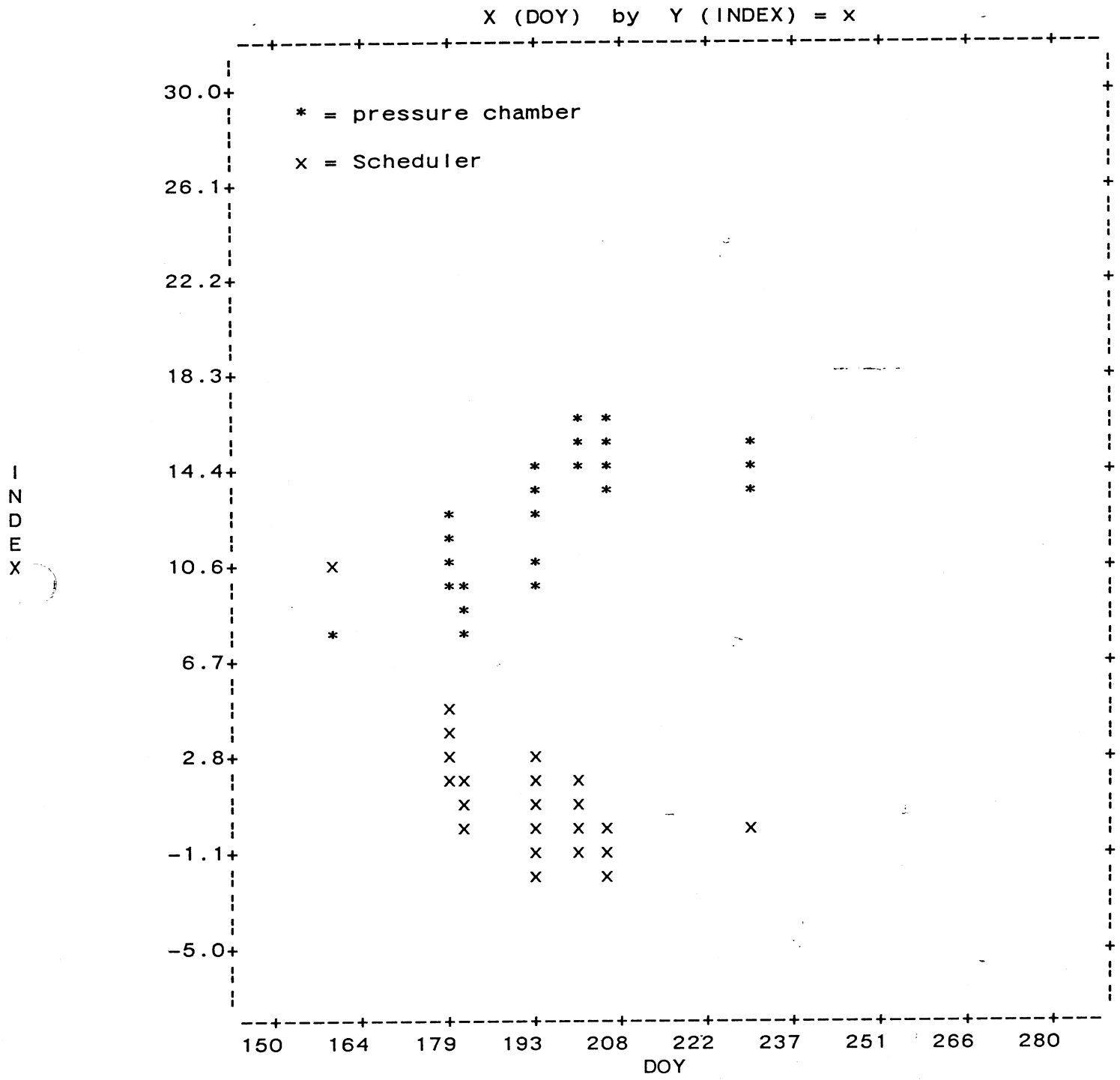


Figure 6. Index and pressure chamber data for the LeMoore site, 1988.

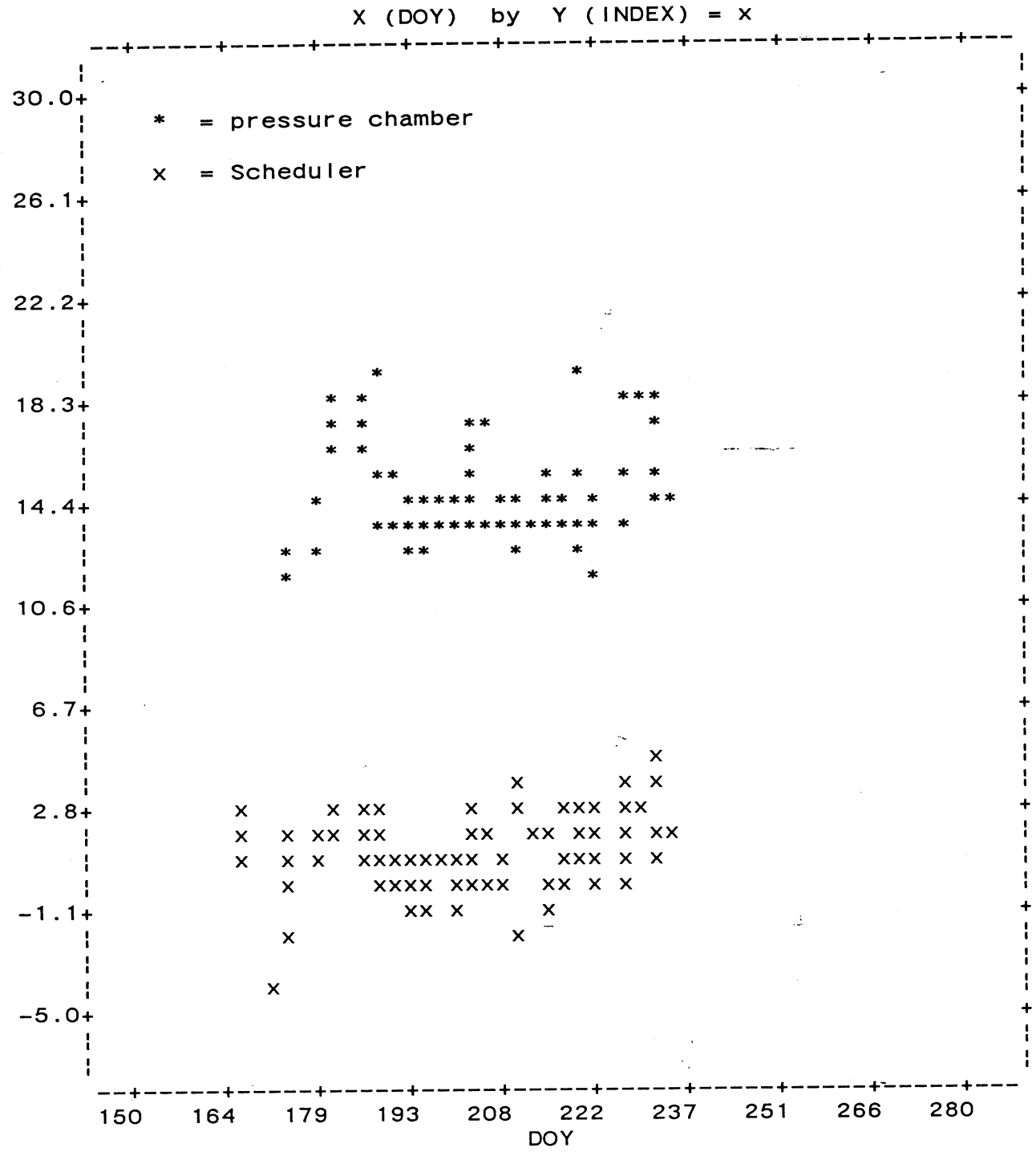


Figure 7. Index and pressure chamber readings for the Merced site, 1988.

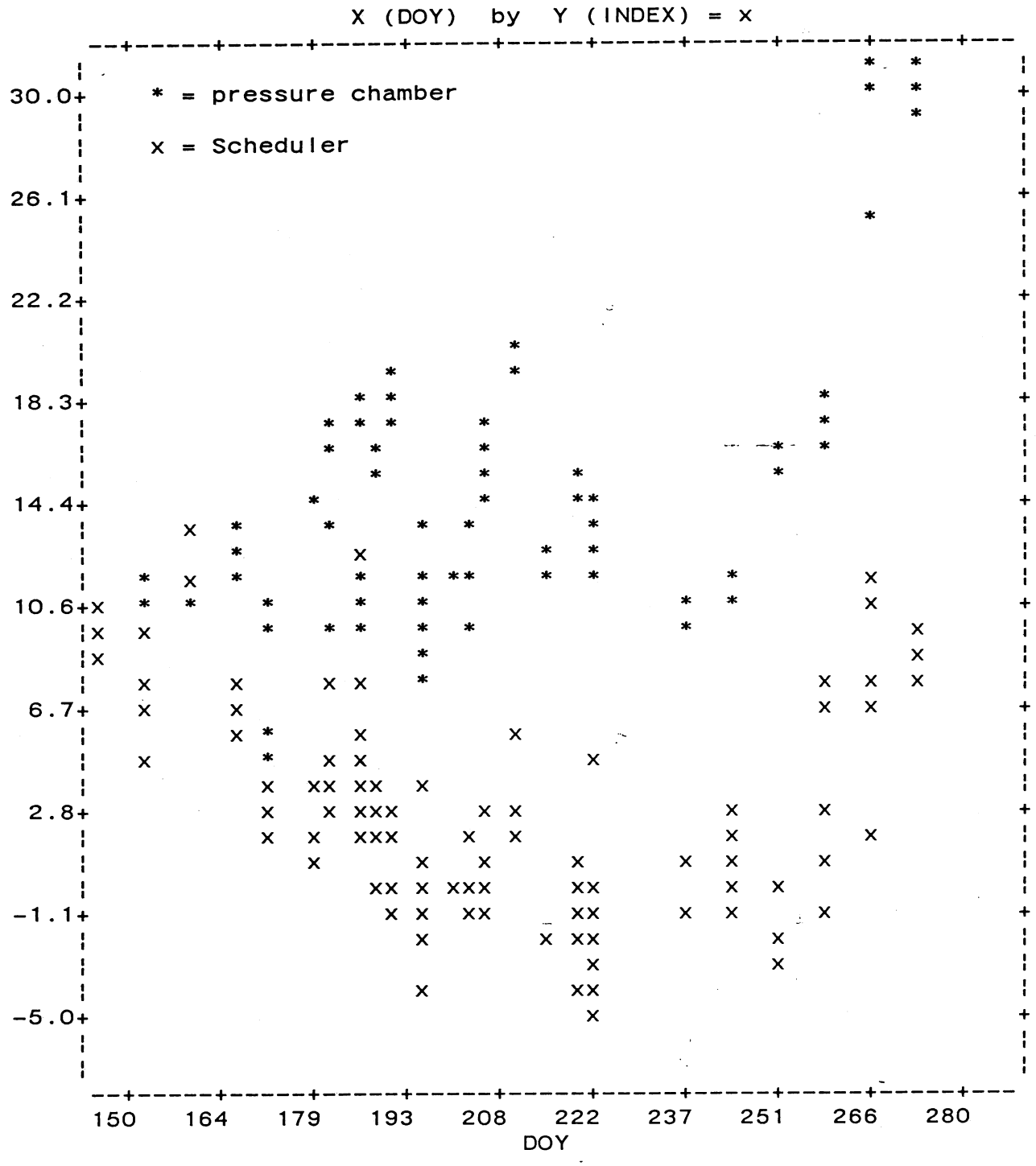


Figure 8. Daily average pressure chamber reading (lwp) verus daily average stress index for the West Side, Merced and LeMoore sites in 1988.

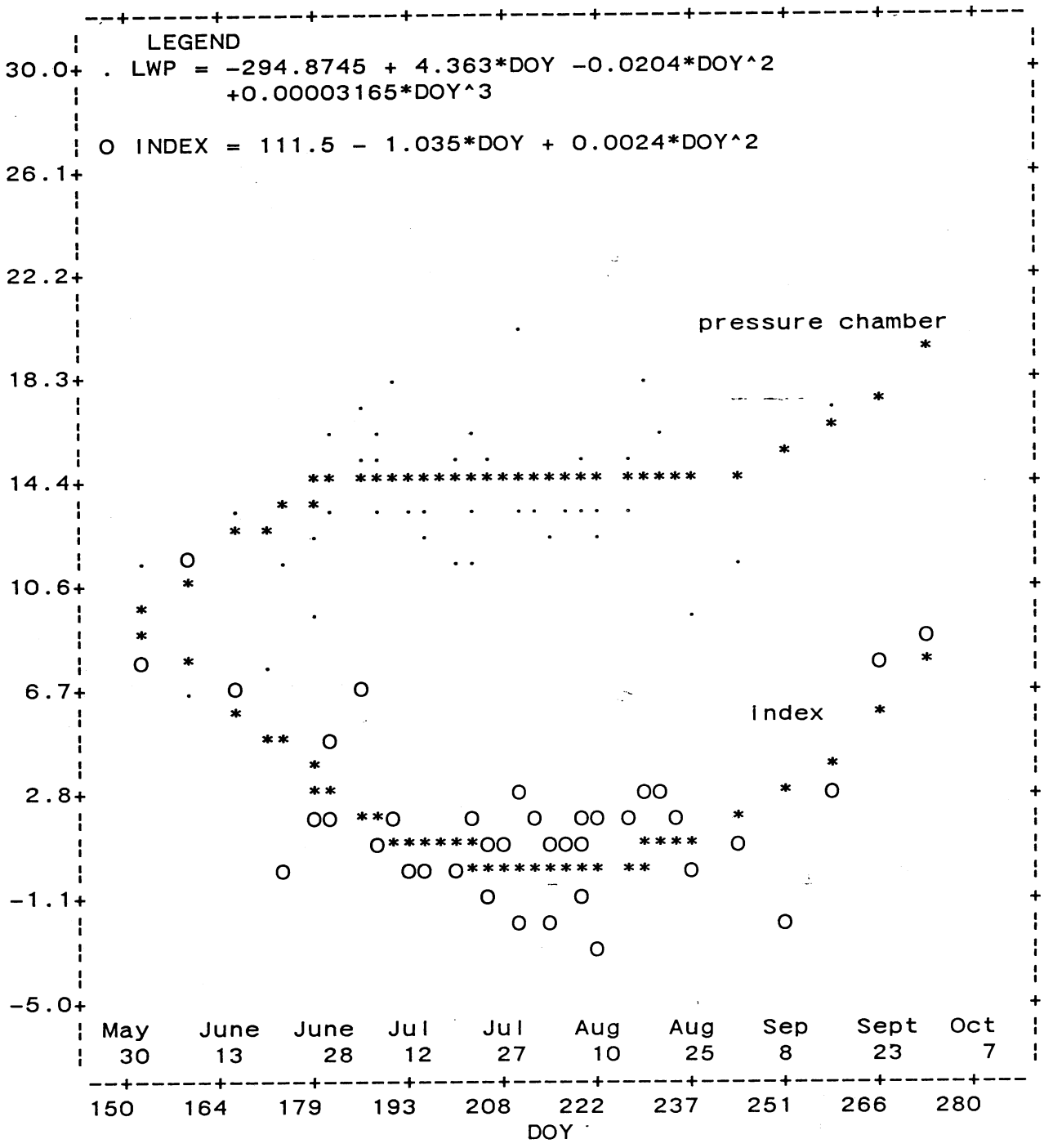
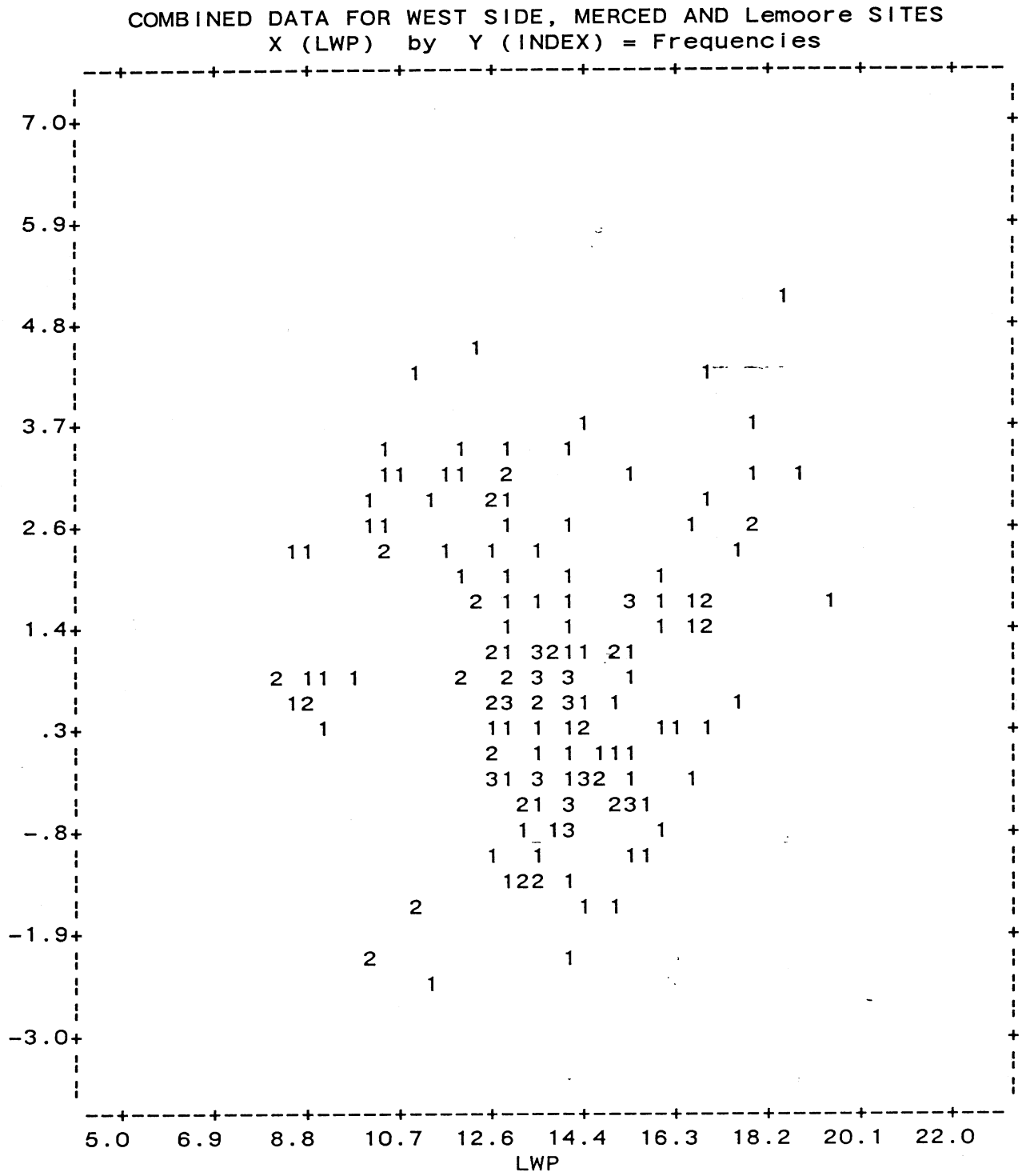


Figure 9. Relationship between pressure chamber readings (lwp) and Scheduler stress index for the combined data from the West Side, Merced and Lemoore sites, 1988.

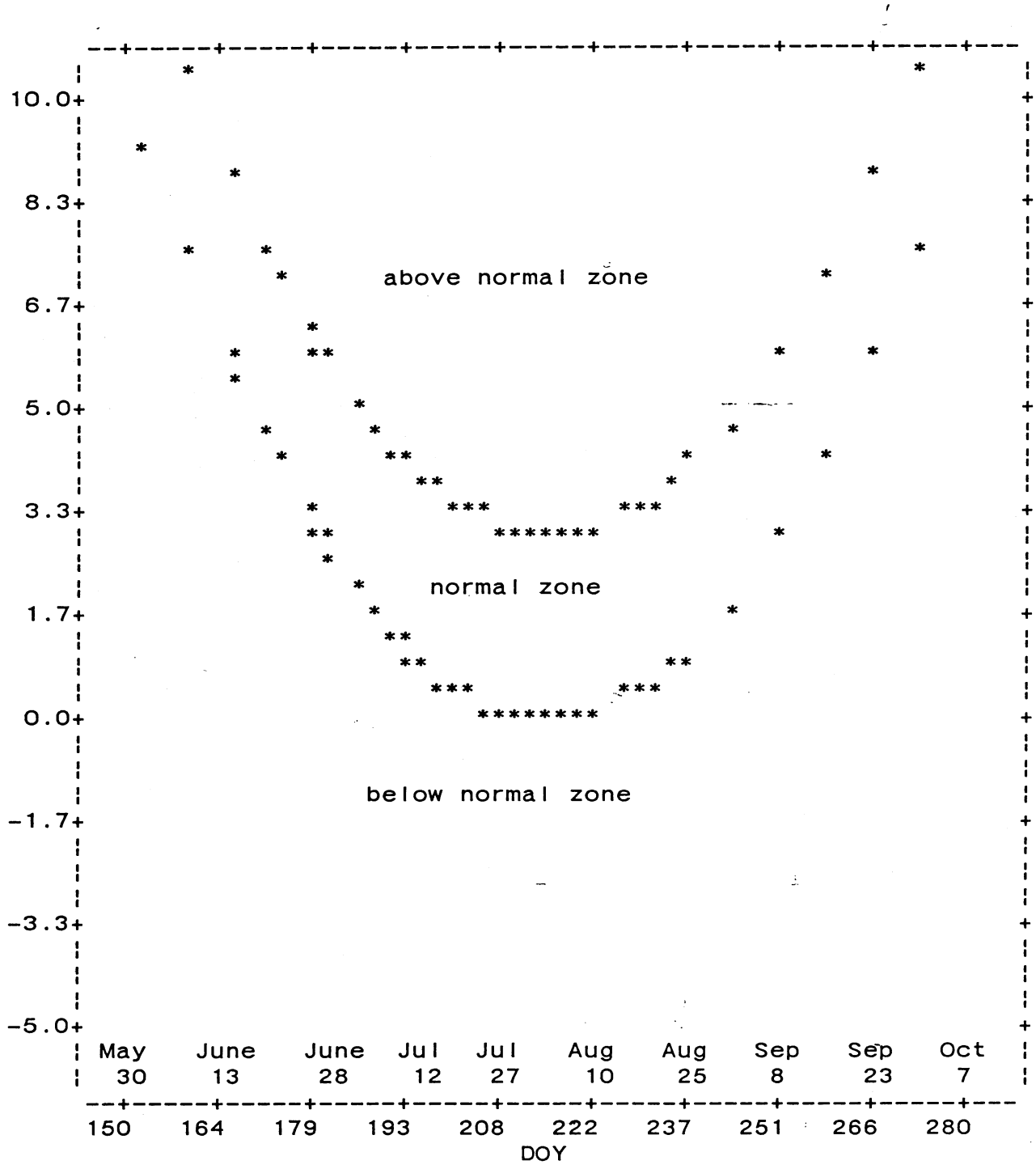


Summary

The relationship between pressure chamber and Scheduler index readings is non-linear. This makes it unlikely that an equation which directly predicts pressure chamber readings based on index readings can be developed.

The best approach to using Scheduler readings for irrigation scheduling is to develop a set of standard index curves for the season (figure 11). Growers could then compare their measured index readings with the standard readings to determine if irrigation is required.

Figure 11. Zone of normal Scheduler index values for well-irrigated cotton in 1988. Combined data from Merced, West Side and Lemoore, California. The zone is 3 stress units wide.



CHAPTER 9 - OTHER WATER MANAGEMENT METHODS

9.1 Irrigation Scheduling

The scheduling of irrigations, also known as water management by those wishing to charge for it, is just the process of answering two questions.

1. **WHEN TO IRRIGATE?**
2. **HOW MUCH TO APPLY?**

Actually, the first question is the only important one. If each irrigation is applied on time, there will be no plant stress. The proper answer to the **"WHEN"** question is:

As soon as the transpiration rate of the plant is greater than the ability of the soil to supply water to the root system.

If the irrigation is applied at the proper time, it generally will not matter to the plant if the quantity is too much or too little, as long as the amount of soil moisture is increased to the point where water stress will no longer occur.

The second question, **"HOW MUCH"**, affects the efficiency of the irrigation operation assuming the timing of the water applications is correct. If the irrigation is scheduled at the right time to avoid stress, but the amount is insufficient to bring the soil back to field capacity then the only problem will be the fact that the next irrigation will have to take place sooner than it would if the quantity had been correctly applied. If the irrigation amount is excessive, the root zone will be filled to capacity and the excess will drain down and

be wasted. This is only an economic problem unless the soil has poor drainage. Certainly the quantity of the irrigation is an important calculation as anyone paying a power bill or faced with a drain water disposal problem will attest. However, it must be remembered that the most sophisticated and accurate quantity measurement is worthless unless the the irrigation is properly timed to prevent crop loss due to water stress.

The most successful irrigation scheduling method based on these criteria would be the one that most consistently is able to indicate the imminence of plant water stress. The required accuracy and precision of the method would depend upon the value of the crop and cost of water, power and labor.

9.2 Methods Of Irrigation Scheduling

There are four basic irrigation scheduling methodologies:

1. Calendar
2. Soil Moisture Monitoring
3. Water Budget or Et Scheduling
4. Plant Stress Monitoring

Rarely can you use only 1 of these methods. You should combine at least two of these methods.

9.2.1 Calendar Scheduling

This is the oldest, least sophisticated and most widely used method of irrigation management. It consists of simply deciding in advance when the irrigations will take place and then applying the water on that schedule. It may be the only possible method if a grower's water supply comes from a district canal on a set schedule. It can be quite effective where water is cheap and abundant and no drainage problems

are present. If the calendar always calls for an irrigation before stress occurs and sufficient water is applied, the method would be successful as long as the economic penalties of excess water application were not significant. Drip systems are often operated on the simplest of calendar schedules, they run every day. There is a danger on some soils and with some crops that excessive water application can cause water stress due to saturated soil conditions. In these instances, a combination of the calendar scheduling with plant stress monitoring (method 4) would be in order.

9.2.2 Soil Moisture Monitoring

The oldest method of irrigation scheduling that actually utilizes a measurement of the soil-water-plant environment is this one. There are several ways in which the soil moisture conditions can be measured. Some devices respond to the water potential of the soil, others to the actual water content. As discussed in Chapter 1, the water potential of a soil is a measure of how easily water can be taken up by roots while the water content is simply a value for the quantity of water in the soil. Either potential or water content can be used for scheduling purposes. There are advantages and disadvantages for each.

Methods that measure water potential are better for answering the question of **"WHEN"** because the water uptake process that must match the transpiration rate to prevent stress is dependent upon maintaining a high soil water potential. If stress begins for grapes on a hot summer day at a tensiometer reading of 60 or a resistance block value of 125, then that reading will be an indication of stress for that crop and those conditions for any soil at any future time.

Knowing the water potential of the soil may be a good indicator of when to apply the water but some measure of water content is necessary to decide **"HOW MUCH"**. When the irrigation date is determined, the amount to apply can be calculated with a device like a neutron probe that responds to the water content of the soil. It would appear from this discussion that a grower or consultant should use something like a tensiometer to determine irrigation date and then a neutron probe to decide how much to apply. While that is possible it is not really necessary. There is a relationship between the potential and the water content for each soil. That relationship, called the "characteristic curve", is used to estimate the water content from a measured potential or the point at which all the high potential water is gone by using a properly calibrated neutron probe.

Irrigation scheduling by the soil moisture monitoring method requires considerable knowledge of the soil which may mean a great deal of laboratory work to determine the soil characteristics. It is most often used in permanent crops where the measuring points are the same each season and the manager can develop a history and experience with the use of the data from the instruments. It is most difficult to use when there is incomplete knowledge of the crop and soil. The primary problem with its use is the fact that there is no direct indicator of the plant water stress point. The manager has to guess the correct water potential or water content of the soil at which the plant will begin to stress. That is a little like waiting for the bank to send you a notice that your checking account is overdrawn before you deposit more money. By the time you are aware of the problem, it is too late to prevent it.

9.2.3 Water Budget or Et Scheduling

If using soil moisture monitoring is similar to not keeping a checkbook up to date then the water budget method is like hiring a CPA to maintain your checking account. The process is very similar to accounting, except the columns in ledger book are in millimeters or inches of water rather than dollars. The root zone in the soil is like the bank. The amount of water in the root zone is the balance in the account and there is one check written each day, evapotranspiration. The problem is that all of these figures have to be estimated and then used to recalculate the new balance. The great advantage of water budget scheduling is that it is so adaptable to computerization. Like many accounting programs, the Et scheduling program requires so much data and calculation that it is really only practical on a computer. The power of a computerized scheduling system enables the user to keep track of numerous fields on several farms in much less time than it would take to read the tensiometers on just a few fields in one area.

The primary disadvantage of the water budget is the fact that all of the work is done indirectly. If one could be sure that the initial set-up data and the daily Et inputs were correct, the scheduling could be done in the office at the computer without ever looking at the field. As good as that might sound to an accountant, it should scare the grower or consultant responsible for the management of the field. The possibilities for errors are tremendous and errors in the program tend to get bigger as each little inaccuracy affects each day's calculation.

The way that the water budget is used in almost every instance is as an initial estimate of the irrigation schedule. The predicted amount of soil moisture can be verified by any of the devices used for soil moisture monitoring. A potentially better alternative is to use a direct measure of plant stress such as the CWSI method as a verification of the stress or absence of stress predicted by the water budget program. Et scheduling is likely to be the method of choice for many irrigation managers as long as it is combined with another method that can provide rapid, accurate, frequent verification of its output.

9.2.4 Plant Stress Monitoring

The great appeal of measuring plant stress to schedule irrigations is the fact that it is the plant that the irrigation is intended to benefit; so an accurate, sensitive, easily-used method of measuring that stress would be the most direct way to determine an irrigation schedule. The great problem has been the development of a device that could measure plant stress accurately, sensitively and easily. There are three ways that plant stress can be monitored for irrigation management:

1. The pressure chamber or "bomb"
2. The porometer
3. The temperature difference method.

The pressure chamber has been used for research and some commercial scheduling for a long time. It measures the water potential of the leaf by placing it in a chamber and building up the pressure with a compressed gas. When the gas pressure equals the water potential in the cells of the leaf, water will flow back out of the leaf. The

chamber is constructed so that the cut end of the petiole extends through the lid and a drop of water forced out of the leaf can be easily seen by the operator. As a plant approaches water stress, its cell water potential will decrease so that it requires a greater gas pressure to push water out of the leaf. Experimentation has established the pressure levels for some crops, particularly cotton, to allow the use of the pressure chamber for irrigation scheduling on a commercial scale. Problems with the method are sufficient to limit its use to some adaptable crops. The readings take time and the equipment is larger and heavier than other devices. Some crops are so variable that a large number of leaves need to be measured in order to determine the stress level of the field. For those crops, the pressure chamber is not practical.

The porometer is a complex device that can directly measure the rate of water vapor loss from the leaf. This would seem to be the ideal method since the rate of water loss is the transpiration rate. Unfortunately, the porometer must be in contact with the leaf surface to take the measurement and the way in which the vapor flow is sensed can affect the activity of the leaf. The porometer is one of those instruments that must always be suspected of affecting the very thing that it is supposed to measure. Additionally, the best of the porometers are quite complex, expensive and need constant maintenance and calibration. They are useful for research but are not at all practical for commercial scheduling.

The temperature difference method is an ingenious technique that takes advantage of the fact that transpiration is evaporation of water

and evaporation of water is an energy absorbing process. When a gram of liquid water evaporates, 540 calories of energy are absorbed. A liter of water would absorb the energy in a hamburger while it evaporates. Since the average almond tree may transpire 200 liters of water a day and since there are usually no hamburgers around to disappear, the energy is absorbed as heat from the leaf and its environment. The effect of this process is to reduce the temperature of the leaf when transpiration going on. The greater the rate of transpiration, the greater the amount of cooling and the greater the difference between the temperature of the air and the leaf. Several researchers have worked on the technique and refined its use to the point where it is now useful for commercial agriculture. The most recent advance is the Crop Water Stress Index which allows not only the detection of plant stress but also quantification of the level of stress. The CWSI technique is so recent that it is still being adapted to the spectrum of crops that it can be used to manage. One problem is that the system must be calibrated for particular crops. As the method reaches more advanced stages of development, it could very well become a more popular way to schedule irrigations than any of the others discussed above. It is particularly suited to use as verification of the estimated schedules from the water budget method. The system can collect data more rapidly and easily than any other which would help a field man to keep up with the large number of fields and farms that some Et scheduling programs can manage.

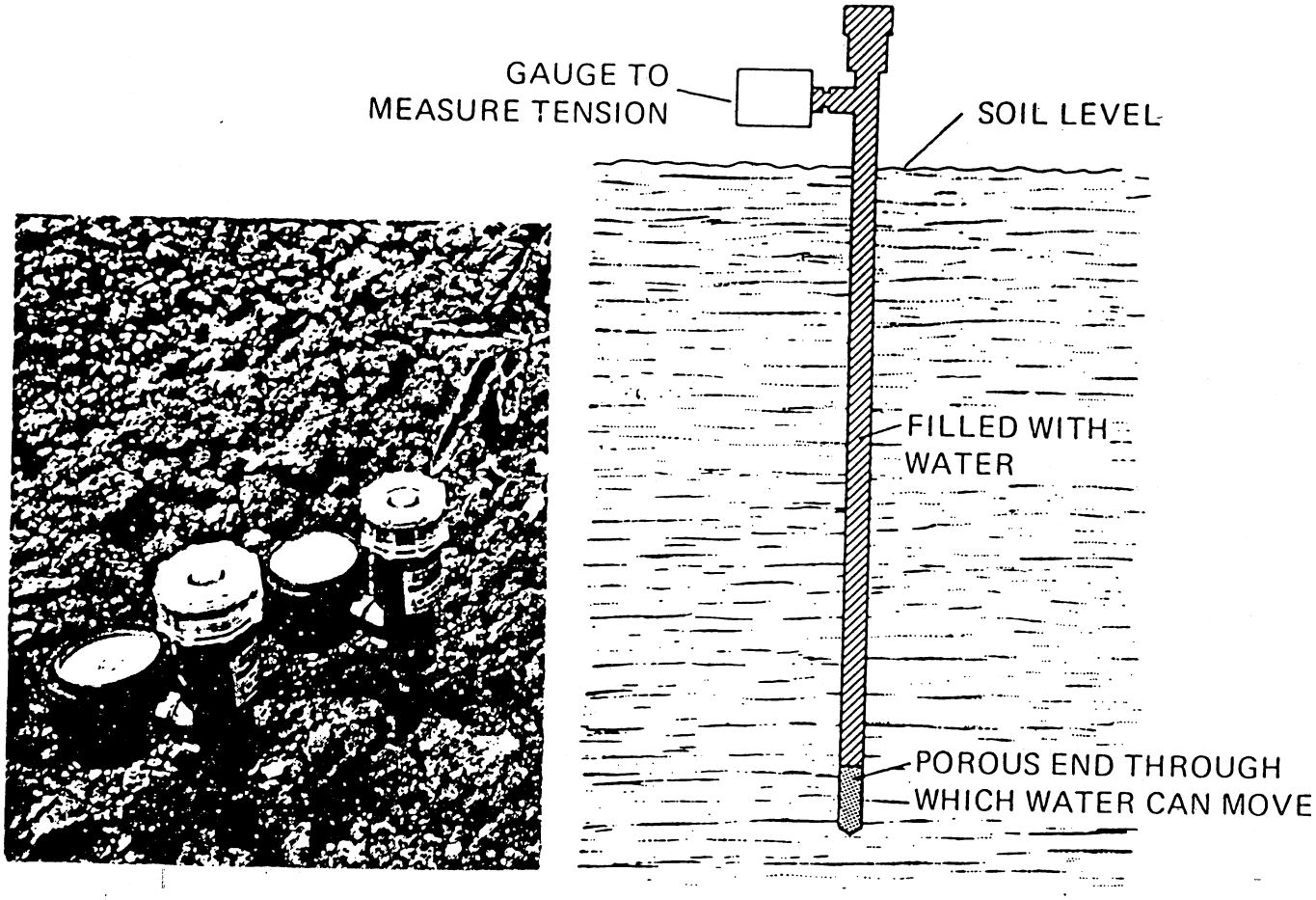


FIGURE 7:9. Tensiometer method of determining moisture stress. (*Left*) Tensiometers in place in the field. (*Right*) Cross section showing essential components of a tensiometer. Water will move through the porous end of the instrument in response to the pull of the soil. This creates a tension which is measured by the gauge. [*Photo courtesy T. W. Prosser Co., Arlington, California.*]

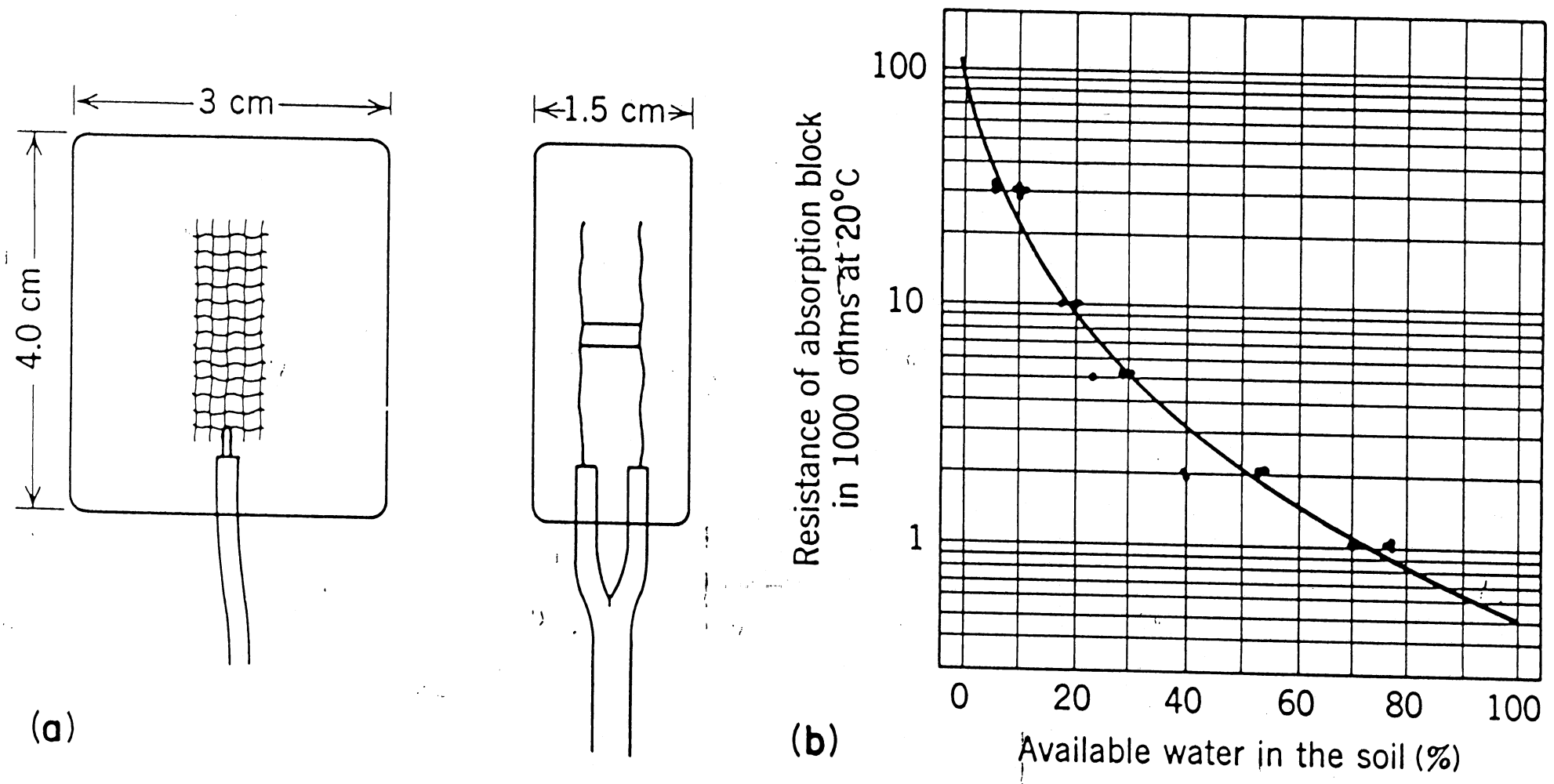


Fig. 4.4. (a) Surface and edge views showing location of electrodes in a plaster of paris block designed to measured changes in soil water content by changes in resistance. The electrodes are pieces of stainless steel screen separated by a plastic spacer and enclosed in plaster of paris. (b) Resistance in ohms of a plaster of paris resistance block plotted over available soil water content of a silt loam soil. (After Bouyoucos, 1954.)

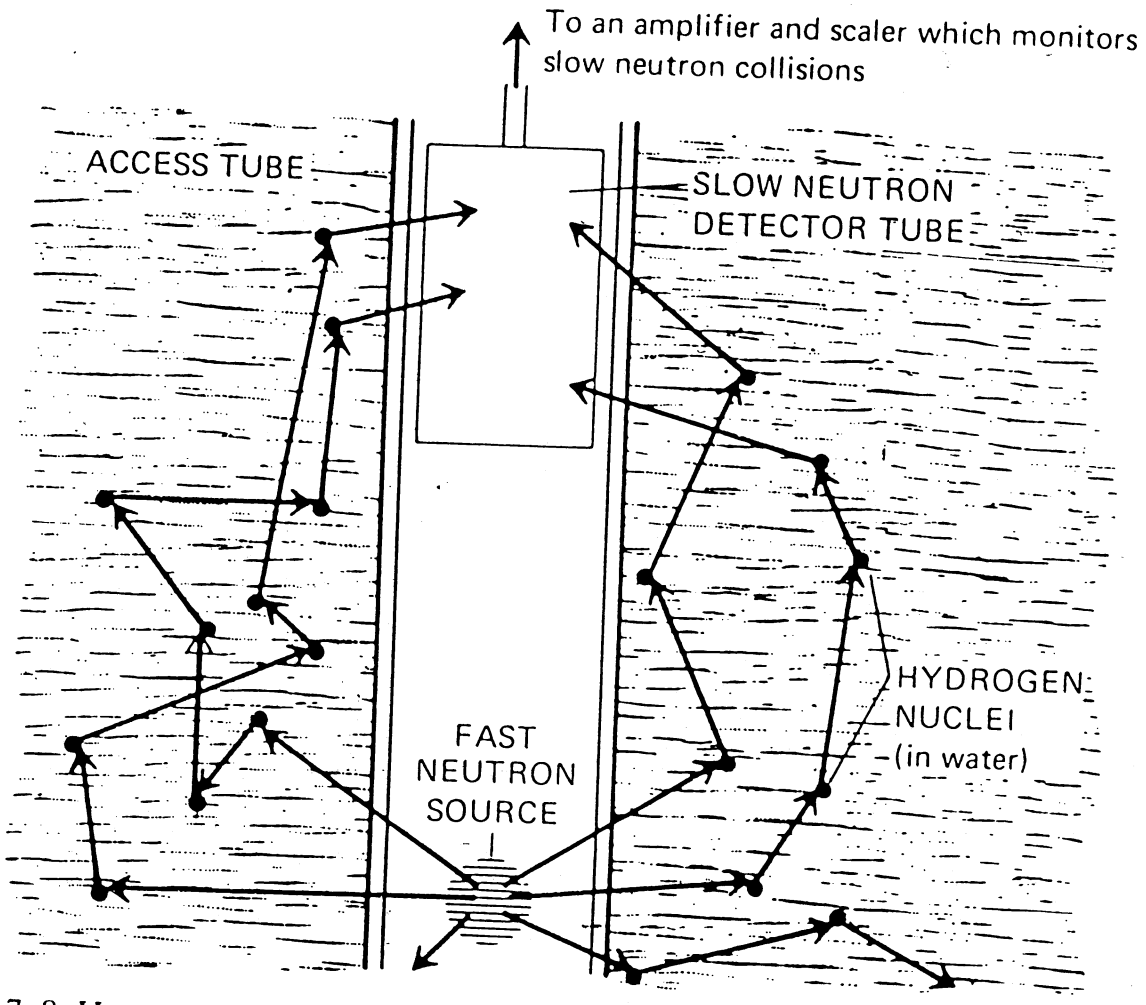

To an amplifier and scaler which monitors slow neutron collisions
ACCESS TUBE
SLOW NEUTRON DETECTOR TUBE
HYDROGEN NUCLEI (in water)
FAST NEUTRON SOURCE

FIGURE 7:8. How a neutron moisture meter operates. The probe, containing a source of fast neutrons and a slow neutron detector, is lowered into the soil through an access tube. Neutrons are emitted by the source (for example, radium or americium–beryllium) at a very high speed. When these neutrons collide with a small atom such as hydrogen contained in soil water, their direction of movement is changed and they lose part of their energy. These "slowed" neutrons are measured by a detector tube and a scalar. The reading is related to the soil moisture content.

CHAPTER 11 - DOWNLOADING TO A P.C.

If there's one problem you don't need when you're showing the Scheduler to a client, its trouble with his p.c. You haven't got the time, nor the interest, in becoming a computer expert (but the customer will think you should be one). So what should you do?

As it turns out, it's relatively easy to solve most of the problems you will encounter. Let's take them 1 by 1.

11.1 Testing the Customer's P.C.

Problem #1. Does the customer's computer have the necessary hardware? The necessary hardware is called an RS-232 port. Have you ever looked on the back of a computer. There can be all sorts of things back there. And none of them marked. So now what? Simple. Do this:

1. Turn the computer on.

2. If a C> appears on the screen, then type "A>" (without quote marks) and press the ENTER or RETURN key.

3. Now that you have an A>, place the special computer analysis disk we gave you into the A drive.

4. Next, type the word "TEST" (without quotes) and press the ENTER or RETURN key.

The program will present you with two options:

1. Test the customer's computer.
2. Import test file.

Select option 1. The program will automatically test the computer. You will see a screen that looks like this:

Status According to RAM

Total Memory	640 Kbytes	Disk Drives	2
I/O Memory	2 Kbytes	Parallel Ports	1
Sys-Brd Mem	64 Kbytes	Serial Ports	2
Video def	80 X 25 color card	Game adapter	YES

The numbers will be different for every computer.

If the customer's computer has the necessary hardware, you will then see this sentence:

"According to RAM, you have 1 (or 2) RS-232 ports"

The program will automatically take you to the next step.

If the customer's computer does not have the necessary hardware, you will see this sentence:

"According to RAM, you cannot down-load a Scheduler to this P.C. An RS-232 card must be installed".

The program will then return to the main menu.

Problem #2. Now that you know the customer has 1 or 2 RS-232 ports, how do you find it. There are two rules:

1. The port has either 9 pins or 25 pins.

2. The port has male pins. Computers also have 25 pin female plugs which are used to connect the computer to a printer. A 25 pin female connector will not work.

You'll have to find these yourself. Just follow the two rules above.

Problem #3. The computer has a 9 pin male RS-232 port, but the Scheduler comes with a 25 pin male plug. All you do is put an adapter between the Scheduler plug and the computer. You should always carry two types of adapters with you:

1. 25 pin female-female adapter.
2. 9 pin to 25 pin female-female adapter.

By this time, you should have been able to learn that the computer should work and make the necessary physical connections.

Problem #4. Is the COM port the Scheduler is hooked up to called COM 1 or COM 2? Who cares anyway? Well, it's an unfortunate computer fact, but you have to learn the answer to this question. The TEST program makes this easy, too.

At this point, the program will take you step by step through the COM port identification procedure. All you'll need to do is answer and few questions which the program will ask and also insert a special RS-232 tester between the Scheduler and the computer.

At this point, you will be ready to down-load a Scheduler into the computer. The program will automatically return you to the main menu.

11.2 Errors/Problems You May Encounter

The test you conducted in section 11.1 covers most of the problems encounted. You may also see some of these:

- Customer's printer doesn't print the graphs exactly as they appear on the screen. The problem is not with the computer or with the software. The problem here is the printer. Many printers have lots of little switches inside that can be set fo make the printer do many things. The printer needs to be in a "GRAPHICS" mode or and "IBM extended character set" mode. You will need to consult the owner's manual for that particular printer. Not a serious problem. The slightly altered graphs are o.k.

- Customer has 1 RS-232 port that he's already using. There are two solutions : have him install another RS-232 card (about $100) or have him buy a special switch so that he can select between the Scheduler and his other device. These switches cost about $40 through the mail and about $150 from a store like Radio Shack.

- Software produces an error message. Sometimes strange things happen with computers. Especially when you are dealing with RS-232 ports. Fortunately, the computer is smart enough to let you know what kind of error has occured. When an error occurs, you will see a message with an error number given. Below are some suggested actions for each error message (there are 52 possible errors, numbered between 1 and 76 (some numbers are not used).

Error Number	Action
1-23,26,29,30, 50,52,54,55,58, 62,63,64,66,69, 73,74,75,76	Phone us, there is a software bug. Make a note of the error and the line number the computer gives you.
24,25	There is a hardware problem with the printer or the RS-232 port. Maybe the printer's not turned on. Maybe someother external device is trying to use the RS-232 port.
27	Put more paper in the printer.

53	A file the program was looking for is missing. This error would occur, for example, if you erase the sample files and then try to load them. This will not cause the software to crash, however.
57	There is a problem with the RS-232 port. Difficult problem to isolate. Sometimes all you have to do is turn the computer off and then turn it on again. This cures a lot of "error 57" problems. It can also indicate a software bug.
61	Your floppy is full. No more data can be stored on it.
67	Your hard drive has too many files on it.
68	Something you tried to use doesn't exist. For example, if you try to import data on a computer that doesn't have an RS-232 card, you will get an error 68
70	Your floppy has a Write Protect Tab on it. You cannot store data on this disk without first removing the tab.
71	You do not have a floppy in your floppy drive (or at least you haven't shut the door).
51,72	Serious hardware problem with floppy or hard drive. See your computer dealer.

11.3 Downloading

You have already successfully down-loaded using the TEST program we provided. This proves that the computer and the Scheduler are working properly. The next step is to download using one of the software packages. To download properly you must:

- Make sure the hardware works right (that's where the TEST program comes in).

- Make sure the hardware are properly connected. Simple things like: Is the connecting cord actually plugged into the Scheduler or into the computer? Again, this should have been verified using the TEST program first.

- Run the MENU program and select the IMPORT option. This option will tell you to make sure that the Scheduler has been set as follows:

Baud Rate	1200
Char. Size	8
Stop Bits	2
Parity	None
Xon/XOff	Disabled

Don't worry about what these things do. If they're not right, though, you won't transfer any data. These things sometimes get changed. There's no harm to the instrument, but these things have to be right for the software to work.

After all this, if there's still a problem, give us a call.

11.4 Computer facts

11.4.1 Floppy Disks Versus Hard Drives

Personal computers permanently store programs and data on one of two types of devices : 1) floppy disk or 2) hard drive. Floppy disks come in two basic sizes : 3 1/2 inch and 5 1/4 inch. A 5 1/4 inch floppy costs about $1. A 3 1/2 inch floppy costs about $4. Hard drives are motor-driven devices which are usually found inside a p.c. They operate faster and store more information than a floppy.

Computers differ greatly in their ability to store information. The units computers store information in is called "K". Older p.c.'s can store only 180K on a floppy. Many p.c.'s can store 360K on a floppy. Some p.c's store 720K, and the latest p.c.'s can store 1200K. In contrast, hard drives can store 10,000K, 20,000K , 40,000K or more. Hard drives cost between $500 and $1,000.

The table below compares the storage capacity of hard disks with floppy disks according to the storage ability of a computer.

MEMORY CAPACITIES OF VARIOUS HARD DISKS	FLOPPY STORAGE ABILITY			
	180 K	360 K	720 K	1200 K
	Equivalent number of Floppies			
10000 K (10 MEG)	55	27	15	8
20000 K (20 MEG)	110	54	30	16
40000 K (40 MEG)	220	108	60	32

11.4.2 Sources For Parts

Radio Shack

RS-232 tester
Cables
Connectors
Gender Changers
Floppy disks

GLOBAL Computer Supplies (low prices)

1-800-845-6225
Calif. 1-213-603-2266
Ga. 1-404-923-5500
Ill. 1-312-627-8800
N.Y. 1-516-752-2299

Serial-Parallel Converter, Switch Boxes

Get a copy of this magazine: COMPUTER SHOPPER (about $3.50). It's loaded with sources.

CHAPTER 13 - SOFTWARE PROGRAMS

Three software packages are available to help a customer use his Scheduler effectively. We have written two of the programs, the third is a commercially available product. The products features are summarized briefly below:

13.1 Niche Software (Commercially available)

Computer Requirements: 1 hard disk with 1500K of memory available (between 1% and 10% of total hard drive capacity).

640K RAM. Many computers have 512K and some have only 256K. NICHE will not run on these other computers.

Graphs:

The program will print a 120 day history graph of any individual field.

Printed reports:

List index value by field
List irrigation dates by field
List Pesticide dates by field

Utilities:

Import Scheduler data

Convert Scheduler data to an ASCII file one field at a time. (If you want all your fields converted to an ASCII file, it takes a while).

Scheduler field numbers can be converted to field names for easier identification.

13.2 Production Software

Computer Requirements: 256K RAM. Program will run from floppy or hard drives.

Graphs: This software graphs two data files:

TODAY's DATA: Just the information collected today.

HISTORICAL DATA: All the information ever collected (index values, crop temperature, air temperature, etc.) The Historical Data file is composed of information from both the Scheduler files: "TODAY's DATA" and "HISTORICAL DATA."

Graphs for TODAY's DATA:

Horizontal Axis	Vertical Axis
Time	Crop Temperature
Field Number	Air Temperature
	Relative Humidity
	Sunlight Reading
	Stress Index
	Crop-Air temperature

This makes 12 graphs. The information which is plotted can be selected by field and by crop.

Patterns of TODAY's DATA: The software will show you two patterns for each crop in your Scheduler:

- Relative Temperature Patterns--to show you where the hot spots are.

- Relative Index Patterns--to show you how much difference in stress levels between areas existed.

Historical Graphs: The same 12 graphs avaialable for TODAY's data are also avaialable for the historical file. Six additional graphs can also be made showing the time trends of the 6 vertical axis variables. Any interval of time can be selected. The graph can also be selected by field and by crop.

Printed Reports: TODAY's data and HISTORICAL data (all information) can be printed:

- By field
- By crop
- By date (any interval from 1 day to 1 year)

Utilities

- Import data. The program automatically determines what type of data you are importing (Historical or Today's) and automatically stores it properly.

- Sample File. Sample data can be automatically loaded for demonstration purposes.

- Setup. Tell the computer what drive to store data on, what communication port you plan to attach the Scheduler to and what crops you have your Scheduler configured for.

13.2.1 Set-Up Procedure for PRODUCTION Software

Create a sub-directory for your programs

NOTE: <RETURN> means press the ENTER or RETURN key.

C: drives

Copy your program disk into a sub-directory. For example, to copy your program disk into the sub-directory R&D:

```
C:            <RETURN>
cd\           <RETURN>
mkdir PROD    <RETURN>
cd\PROD       <RETURN> then place your program disk in the
                       A: drive and
copy A:*.*  C:*.*   <RETURN>
```

Your program disk now has been copied into the subdirectory PROD.

13.2.2 Running the Program

C: drives The commands are:

C: <RETURN> **CD\PROD** <RETURN>
(if PROD is the name of the sub-directory you copied the program disk into) **MENU** <RETURN> **A: drives**

Step 1. Insert the program disk into the A:Drive.

Step 2: **Make sure you have the A> on the screen.**

Step 3: The command is:

MENU <RETURN>

13.2.3 Initializing the Program

The MAIN menu provides you with several options. Press "S" to select the "SET-UP" routine.

The set-up program will ask you to

1. Define which drive the programs are stored on (the C drive, usually).

2. Define which drive the data data will be stored on (the A drive, usually, but you can use the C or B drives).

3. Select the scale for the temperature (C or F).

Your resonses will be stored in the file "Setup.dat". This file is needed to run the program.

13.3 R&D Software

The R&D Software is virtually identical to the Production Software. The major difference is that two additional variables are added (VPD and STD) and up to 240 fields can be analyzed. This software will be available shortly.

13.4 Scheduler Software Summary

General

- Easy to use. Only eight buttons to push (ON/OFF, HELP, PRINT, DEL,ENTER, UP, CALC, DOWN). No computer experience needed.

- Seven pre-programmed crops per unit.

- RS-232 compatible for down-loading to external computers and printers.

- Easily replaced EPROM's for changing between software programs. (Currently this change is made for the user only by our technicians).

- Modem communication for easily changing crops and their associated baselines.

- Real-time clock.

- Battery test feature.

- Visual display of the difference between crop and air temperatures.

- Sunlight level feature to automatically delete any data collected at less than 65% full sunlight. The user can enable or disable this feature at will.

Production Software

- 15 day data storage for stress index values for each of 30 separate fields or locations.

- Graphical display of the stress index trends for the most recent 15 days for each of 30 fields. This allows rapid in-field decisions without using an external computer.

- One-day storage of mean values of crop, temperature, air temperature, relative humidity, solar radiation and the stress index. Also stores the time, date and number of samples associated with each average. Means are automatically deleted at mid-night.

R & D Software Features

- One day data storage for average values of crop temperature, air temperature, relative humidity, solar radiation and the stress index for 240 separate fields. Standard deviation of crop temperature, vapor pressure deficit, date, time, field number, crop name, and number of samples collected with each average. No data is deleted automatically.

- Ability to transmit all data in real-time to an external RS-232 device, making it possible to capture all the data observed by the Scheduler^{R}.

- Switchable between ^{o}C and ^{o}F.

SCHEDULER^{R} PLANT STRESS MONITOR

USER SCHOOL

AGENDA

THURSDAY, MAY 4, 1989

9:30 – 9:35 AM:	Introduction
9:35 – 10:00:	Infrared Crop Management – Proper Sampling Procedures – Proper Aiming Technique
10:00 – 10:30:	The Stress Index – Use and Guidelines – Using Trends for Success – Factors That Affect The Stress Index
10:30 – 10:40:	Break
10:40 – 11:30:	PC/Printer Communications Software Demonstrations
11:30 – 11:45:	Trouble Shooting Maintenance
11:45 – 12:15:	Questions/Group Discussion
12:15 PM:	Lunch

Preparing To Take Readings

1. **Batteries**
2. **Clean lens**
3. **Gun temperature**

Field Conditions For Readings

1. Solar noon
2. Bright sunshine
3. Low wind speed
4. Dry foliage

How To Check Operation

1. Temperature of melting ice
2. Temperature of air
3. Relative humidity

Proper Method To Make Readings

1. Stand inside field
2. Keep the sun directly at your back
3. Hold gun 3 feet above the crop canopy

Proper Method To Make Readings

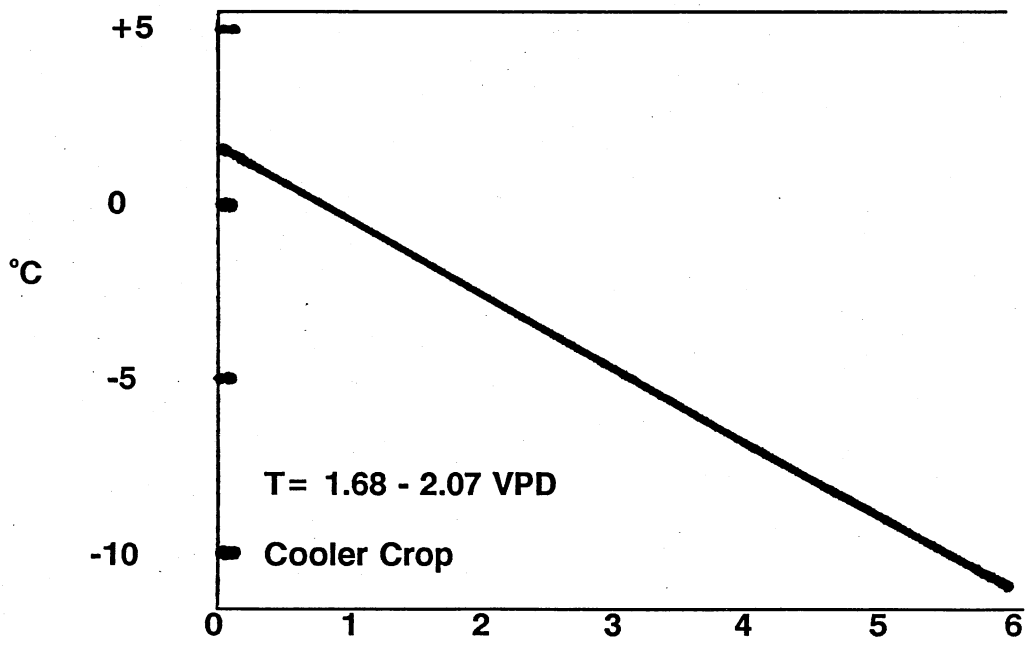
4. Aim 30 feet from you into the crop

5. Aim at least 2 seconds before pulling trigger

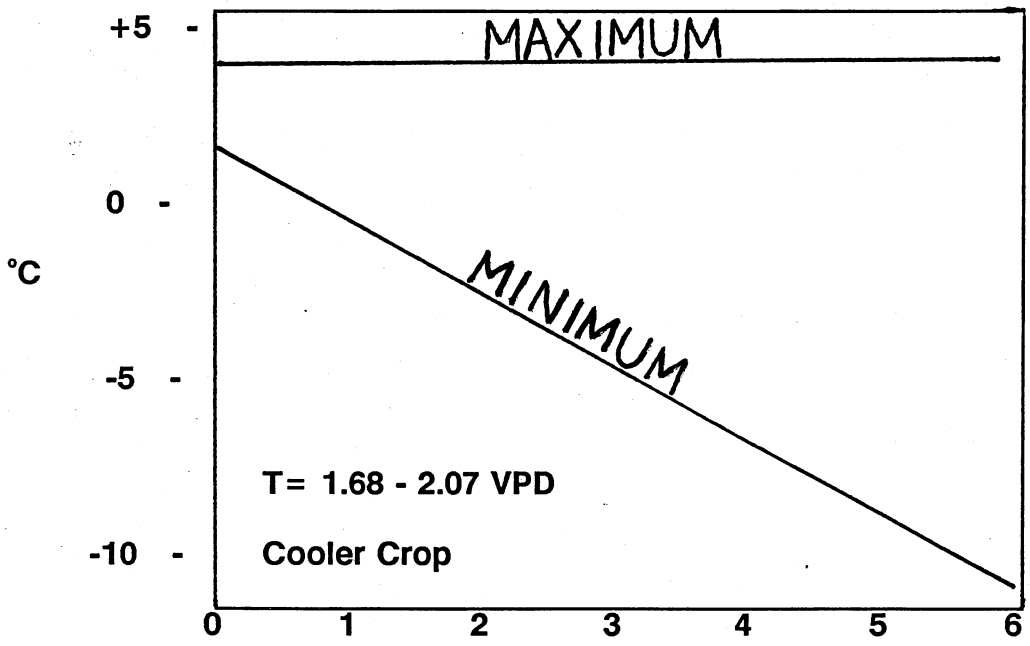
6. Make multiple measurements, 10 to 20 per location.

Irrigate According To Proven Relationships

Non-stressed Baseline for Canopy Cooling of Sugar Beets
Malheur Experiment Station, OSU, Ontario, OR, 1987 and 1988.

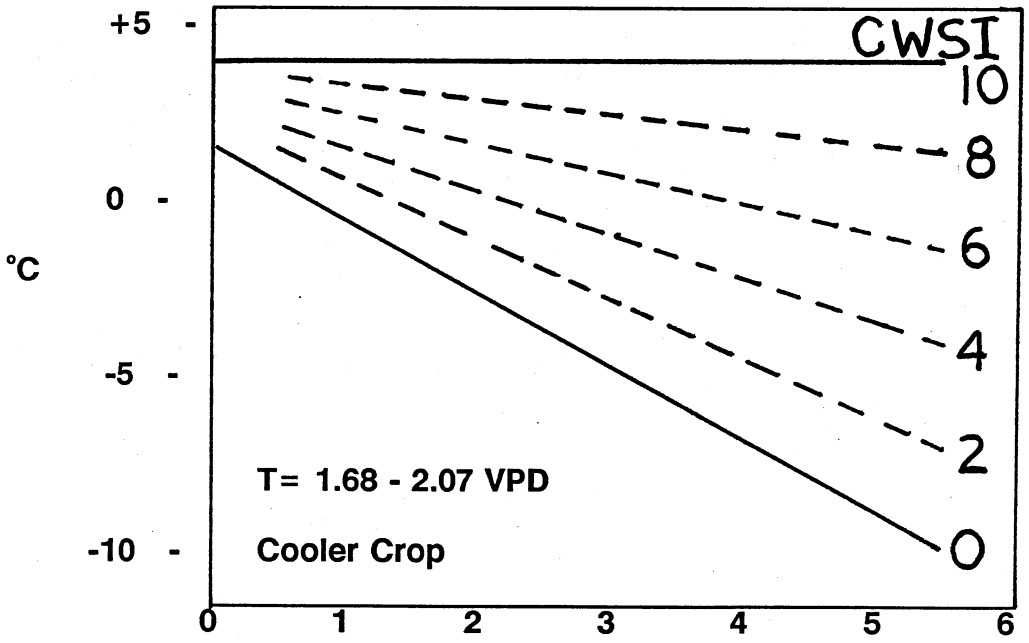


Non-stressed Baseline for Canopy Cooling of Sugar Beets
Malheur Experiment Station, OSU, Ontario, OR, 1987 and 1988.



Non-stressed Baseline for Canopy Cooling of Sugar Beets
Malheur Experiment Station, OSU, Ontario, OR, 1987 and 1988.

Leaf Temperature
Minus Air Temperature



Air Vapor Pressure Deficit (kPa)
Drier Air

PLANT STRESS MONITOR

USER'S SCHOOL

MAY, 1989

CARBORUNDUM

formerly

STANDARD OIL ENGINEERED MATERIALS COMPANY

INSTRUMENT TECHNOLOGIES

SCHEDULER^{R} PLANT STRESS MONITOR

USER'S SCHOOL

AGENDA

TUESDAY, MAY 2, 1989

RED LION/PASCO, WA

9:30 – 9:35 am: Introduction

9:35 – 10:00: Infrared Crop Management

* Proper Sampling Procedures
* Proper Aiming Technique

10:00 – 10:30: The Stress Index

* Use and Guidelines
* Using Trends for Success
* Factors That Affect The Stress Index

10:30 – 10:40: Break

10:40 – 11:30: PC/Printer Communications
Software Demonstrations

11:30 – 11:45: Trouble Shooting
Maintenance

11:45 – 12:15: Question/Group Discussion

12:15 pm: Lunch

INFRARED CROP MANAGEMENT

- Proper Sampling Procedures

- Proper Aiming Techniques

KEYS TO SUCCESSFUL SAMPLING

- Step out of vehicle.
- Remove Scheduler from soft-sided case.
- Invert sensor gun.
- Walk a minimum of 50 feet into the field (same area each time).
- Set desired field number and crop name.
- Check for correct time and date.
- Initiate 94 second countdown.

KEYS TO SUCCESSFUL SAMPLING

- Take test reading (at least 5 samples). Repeat over same area until stress index variance is .5 or less between readings.

- Take a minimum of 20 samples per location.

- Number of sample locations per field depends on:

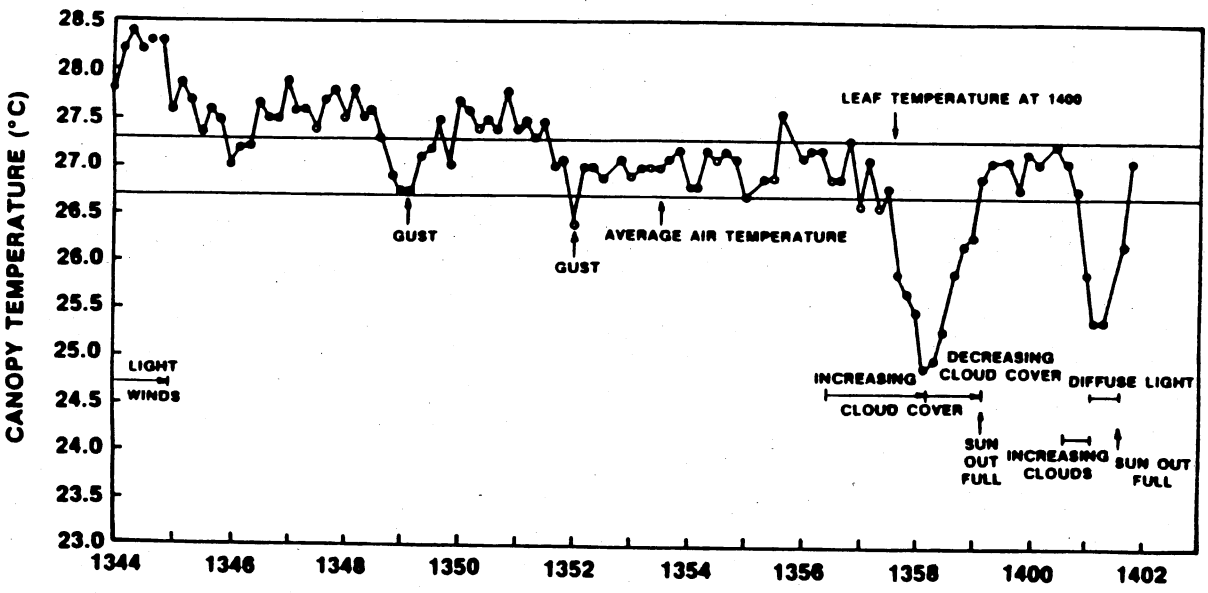
  · Crop size
  · Soil type variance
  · Size of field

- When moving to another sample site within the same field either hold gun or leave it inverted in the holster at all times.

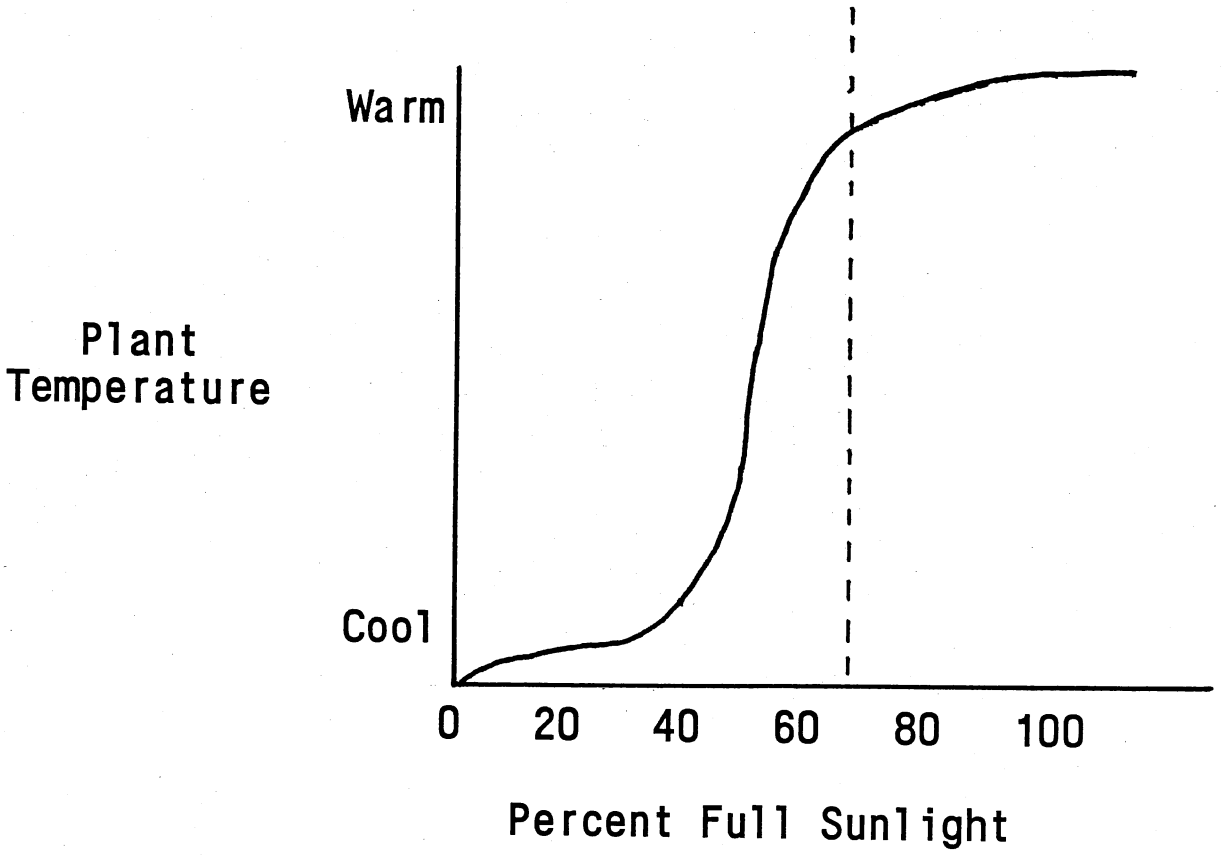
- Sample only during the key sunlight hours (+/- 2 hours solar noon).

- Do not sample under cloudy conditions.

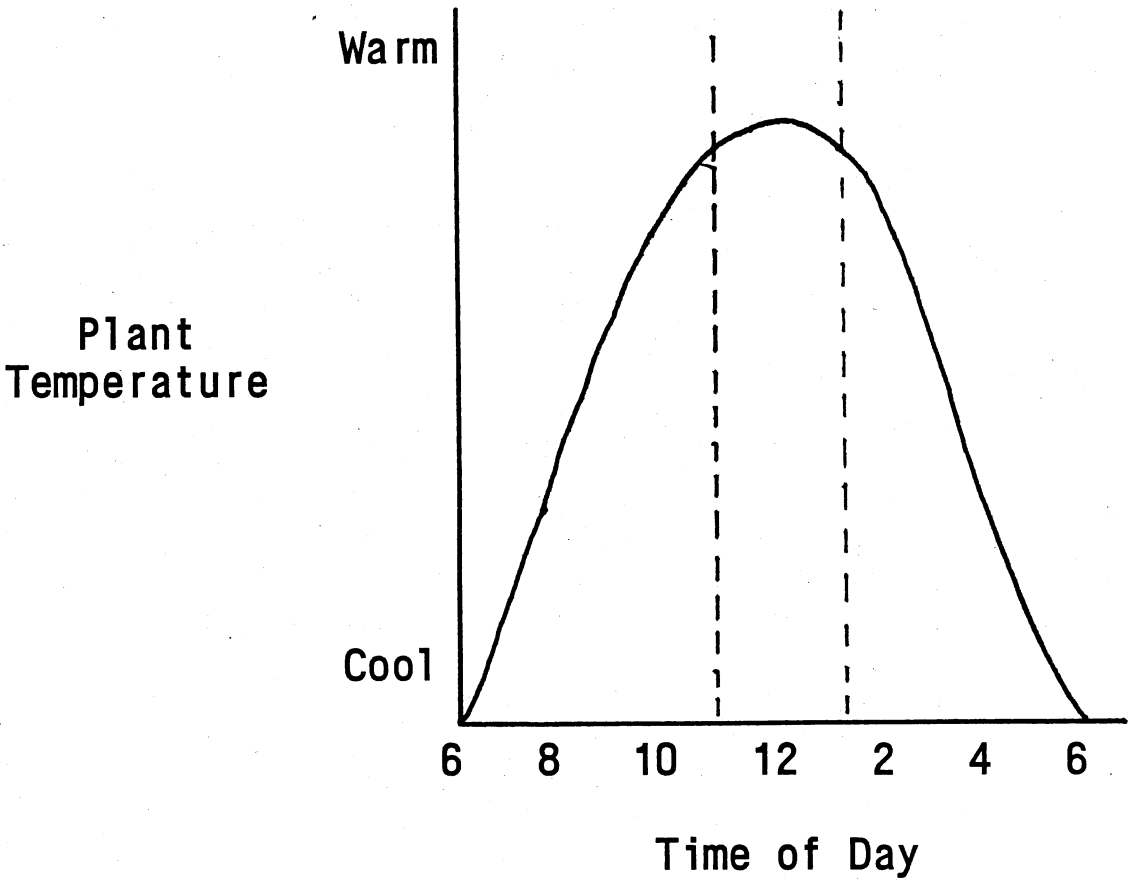
- Only sample dry plants.


CANOPY TEMPERATURE (°C)
28.5
28.0
27.5
27.0
26.5
26.0
25.5
25.0
24.5
24.0
23.5
23.0
1344
1346
1348
1350
1352
1354
1356
1358
1400
1402
LEAF TEMPERATURE AT 1400
GUST
GUST
AVERAGE AIR TEMPERATURE
LIGHT
WINDS
INCREASING
CLOUD COVER
DECREASING
CLOUD COVER
DIFFUSE LIGHT
SUN
OUT
FULL
INCREASING
CLOUDS
SUN OUT
FULL

SUNLIGHT


Plant Temperature
Warm
Cool
0
20
40
60
80
100
Percent Full Sunlight

SUCCESSFUL SAMPLING



PROPER AIMING TECHNIQUE

COMMON MISTAKES

- Aiming too high

- Aiming into a shaded area

- Aiming at soil

- Sampling from roadways

6.4 What an Infrared Thermometer Sees

An infrared thermometer "sees" an oval shaped area (Figure 8), similar in shape to the area lighted by a flashlight. The size of this area is controlled by how high you hold the infrared thermometer above the target area and by how far away the target is from the user.

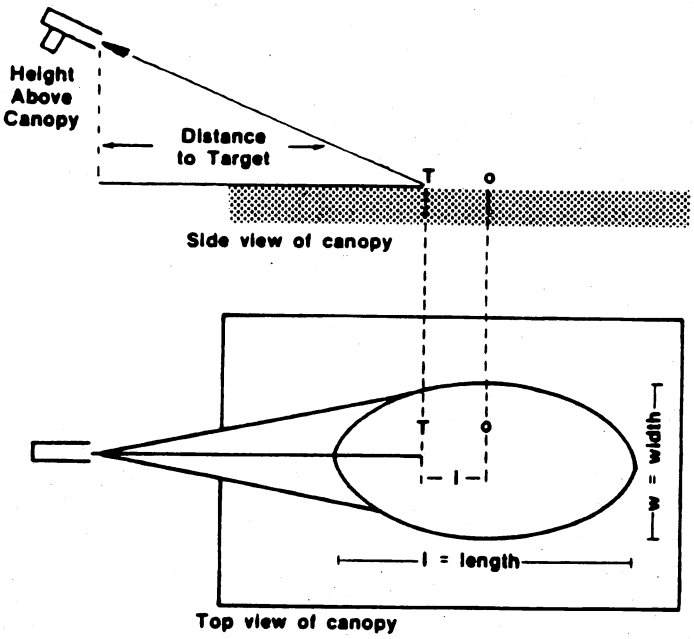


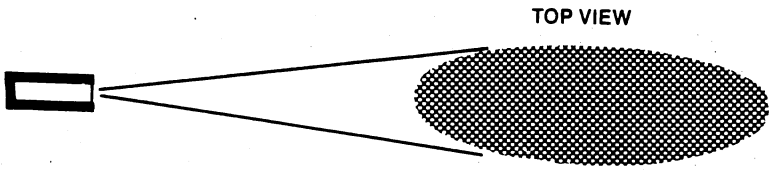
Figure 9

Dimensions of the Zone "Seen"
by the Scheduler Infrared Thermometer

Height Above Canopy (ft.)	Distance to Target (ft.)	Zone Length (ft.)	Zone Width (ft.)	Zone Area (ft.^{2})
3	1	0.5	0.4	.2
3	5	1.6	0.8	1
3	10	5.4	1.4	6
3	20	24.4	2.8	54
3	30	83.0	4.2	274
5	5	1.4	1.0	1
5	10	3.6	1.6	4
5	20	12.9	2.9	29
5	30	31.4	4.3	105
5	40	66.2	5.6	293
5	50	138.0	7.0	762
10	5	1.8	1.6	2
10	10	2.8	2.0	4
10	20	7.1	3.1	17
10	40	25.8	5.8	117
10	60	62.8	8.6	420
10	80	132.0	11.3	1,117
10	100	276.0	14.1	3,051

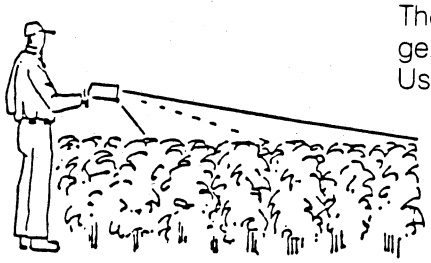
PROPER AIMING TECHNIQUE

How the Sensor Gun Works



Dimensions of the Zone "Seen" by the Sensor Gun

HEIGHT ABOVE CANOPY (FT.)	DISTANCE TO TARGET (FT.)	OVAL LENGTH (FT.)	MAX. OVAL WIDTH (FT.)	AREA VIEWED (SQ. FT.)
3	10	3	1	3
3	40	48	2	120
3	75	550	5	4700
5	120	680	8	8200



The technique for using the Sensor Gun will change as a crop matures. As a general guideline, the gun should never be closer than 3 feet from the soil. Use the following guidelines when aiming at the plant target:

- 25 feet should be the limit to your aim when the Sensor Gun is positioned approximately 1 foot above the crop canopy.
- 75 feet is the limit at 3 feet above the canopy.
- 120 feet is the limit at 5 feet above the canopy.

PROPER AIMING AND SAMPLING

QUICK REFERENCE CARD

SCHEDULER™ PLANT STRESS MONITOR

SAMPLING GUIDELINES

- Always sample the sunlit side of the crop.
- When taking samples, be sure to point the Gun at foliage--not bare soil or the sky.
- The best sampling time is between 11AM and 4PM.
- Hold the Gun one to three feet above the crop canopy.
- Carry the Gun out of holster and in your hand while taking samples in the field.

MAINTENANCE AND STORAGE GUIDELINES

- Always start the season with new batteries.
- Remove batteries at the end of the season or for prolonged storage.
- Never store the Monitor in direct sunlight for a prolonged period (the dash of a pickup truck, for example).
- Never store or use the Monitor in a cold environment (below 50°F).
- Avoid exposing the Monitor to wet or extremely damp conditions.

For complete instructions on use and operations consult the Operator's Manual

THE STRESS INDEX

CROP STRESS INDEX

A calculated index that represents the plant's actual health status based upon:

- Plant measurement

- Field measurement

WHAT AFFECTS THE CROP STRESS INDEX

- Climatic conditions
- Wind
- Frequency of irrigation
- Irrigation volume
- Disease
- Insect damage
- Root growth obstructions
- Physiological stage of growth
- Many others

SPECIFIC RECOMMENDATIONS

POTATOES

Period I: Tuber initiation through mid-bulking

Period II: Mid-bulking through beginning maturity

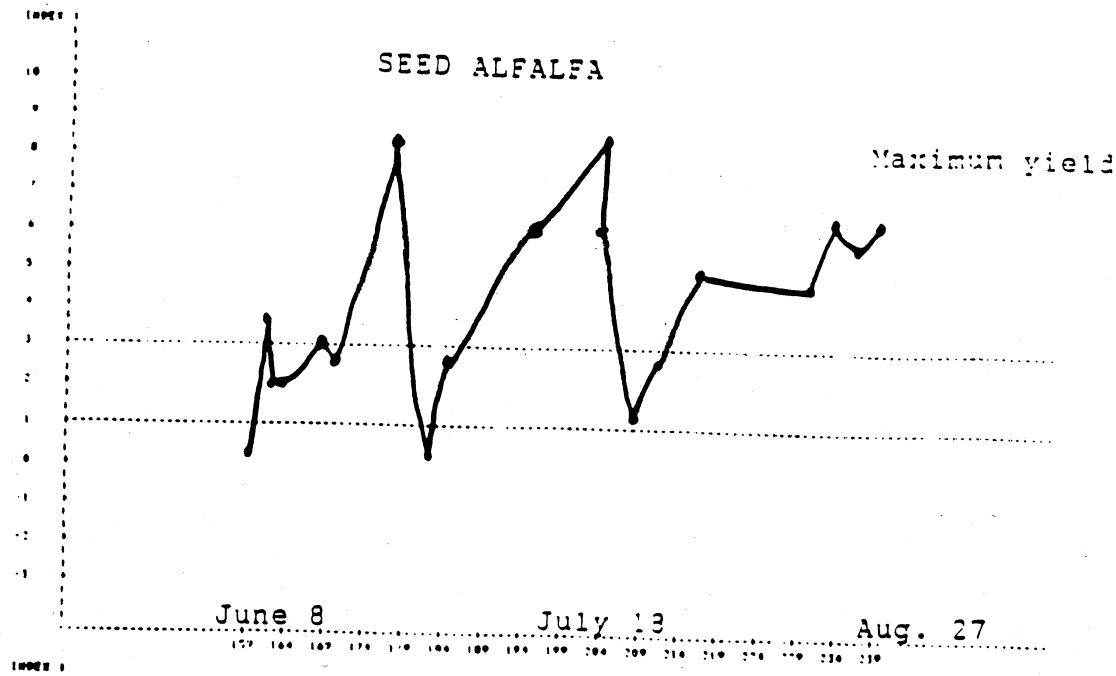
Period III: Maturity through senescence

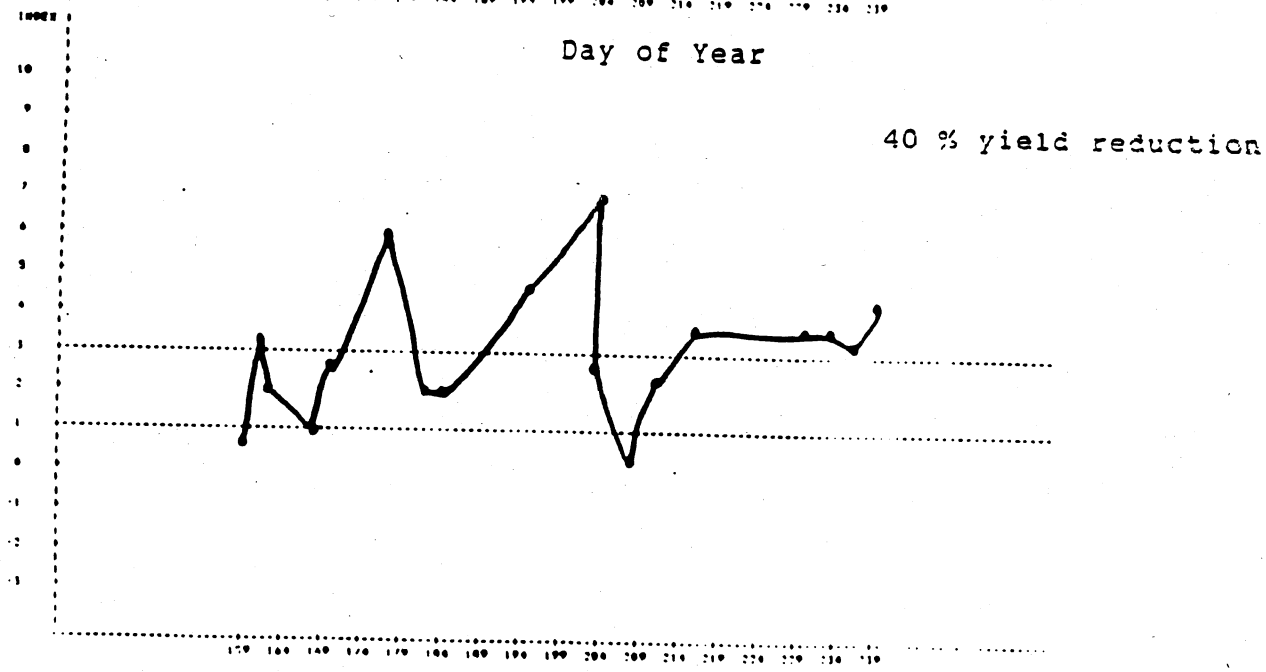
1987 DATA SUMMARY*

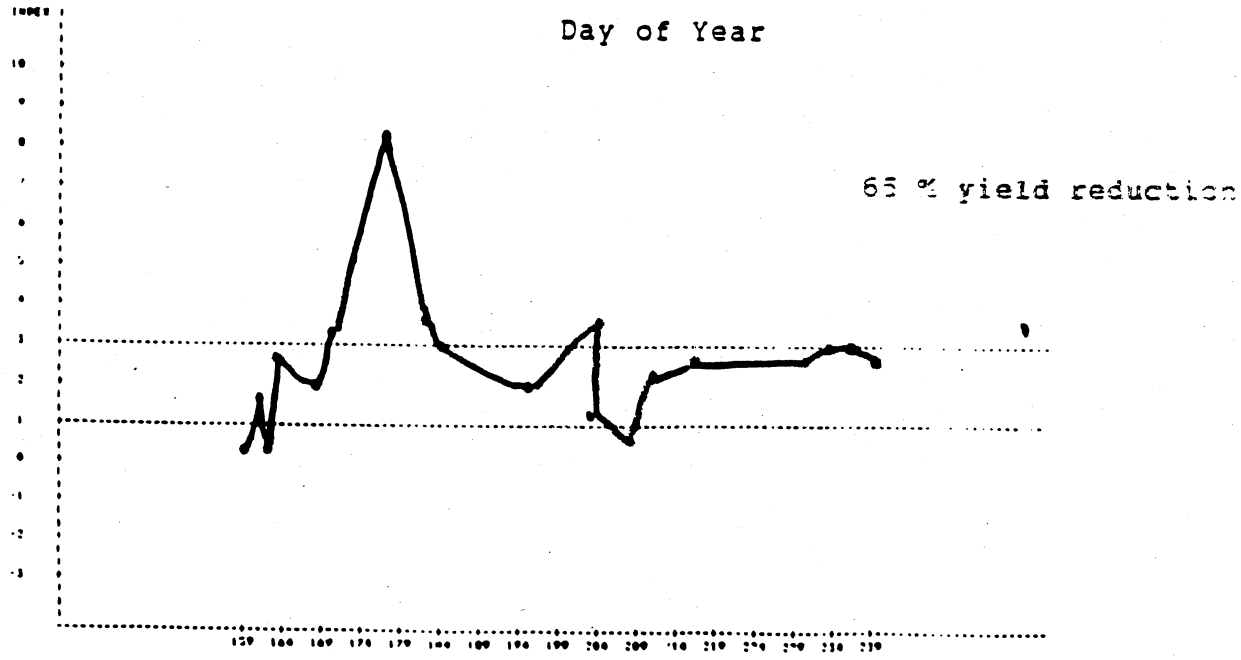
Average Index (Periods I&II)	Maximum Index (Periods I&II)	Percent Maximum Yield	Percent No. 1 (excluding potatoes <4 oz.)
0.3	2.1	83%	62%
0.6	4.0	87%	44%
1.4	5.1	100%	46%
1.9	5.6	81%	37%
2.0	5.5	74%	18%
3.1	5.6	76%	10%

USING TRENDS FOR SUCCESS

Date	Crop	Stress Index
June 15	Alfalfa	+2.3


SEED ALFALFA
Maximum yield
June 8
July 13
Aug. 27
Day of Year


40 % yield reduction
Day of Year


65 % yield reduction

STRESS INDEX — SUCCESSFUL USE

- Use consistently to develop trends.

- Demonstrate proper aiming and sampling technique.

- Observe management practices:
  - Tillage
  - Chemical applications
  - Many others

- Maintain long term records.

- Repetition

PC/PRINTER COMMUNICATIONS

IMPOSSIBLE?

PC CHECKLIST

NEED DOWNLOADING HELP?

Before you call:

- Determine PC DOS version
- PC manufacturer
- Locate PC manual
- Communication card manual
- Communication card manufacturer
- Communication card pin outs

PC CHECKLIST

Does your computer run DOS?

From the C:> prompt, type: VER and press return. The version of DOS will be displayed.

Do you have a hard drive?

If you can turn your computer on without placing a floppy disk in the A: or B: drive, then you have a hard disk.

Do you have one or two floppy drives?

How many slots do you have that can hold a floppy disk.

Do you have an RS-232 port?

The easiest way to tell is to run the Scheduler program. Select the utilities option and press "T" to test you computer. The program will determine how many RS-232 ports you have.

PC CHECKLIST

(Continued)

Can you physically locate the RS-232 port?

Hint: Look on the back of the PC. Any male connector with 9 pins or 25 pins is probably an RS-232 port. If you have a modem or other device attached, this port may already be in service. You may need an A/B switch box.

Are you configured on Com 1 or Com 2?

Unless you have an RS-232 mini-tester, you must guess whether your RS-232 port is called Com 1 or Com 2 (There are only two options possible). If you only have one RS-232 port, your port is probably called Com 1. You can use the "set-up" mode in the software to change between Com 1 and Com 2.

Have you tried to download information from the Scheduler to your computer? If so what was showing on the screen right before, during, and after the downloading procedure?

COMPUTER REQUIREMENTS FOR RUNNING THE SCHEDULER SOFTWARE

256 K Memory

IBM or IBM compatible

TROUBLE SHOOTING

- Check power

- Check on-line status

- Communications matching

- Check cable connections

- Bent or broken pins

- Dip switch settings

SCHEDULER TROUBLE SHOOTING/MAINTENANCE

- Check batteries

- Keep dry

- Cleaning
  - Housing
  - IR lens

- Resetting time and date

- Unusual readings

- Service

(800) 356-0458

The Carborundum Company
Instrument Technologies
6180 Cochran Road
Solon, Ohio 44139

ATTN: Service Department

THIS SECTION HELPS YOU TEST
THE RS-232 PORTS
AND DETERMINE IF A PARTICULAR PORT
IS COM 1 OR COM 2

STEP 1: Attach your RS-232 Mini Tester to a COM port on the PC.

DO NOT ATTACH THE SCHEDULER YET!!!

The TD, RTS, and DTR lights should glow a steady RED. The other lights should be off. If the lights do not match this description, this is not a COM port. You may need to use an adapter.

Press any key to continue ("Q" to Quit)

STEP 2: Test whether or not this COM port is COM 1

PRESS ANY KEY TO TEST
IF THIS IS COM 1

TESTING COM 1 PORT

The RTS and DTR lights should be flashing. If they are not FLASHING, you are not connected to COM 1.

Press any key to continue.

STEP 3: Did RTS and DTR FLASH? (Y/N)

THIS PORT IS COM 1

Press any key to continue ("Q" to Quit)

PRESS ANY KEY TO TEST IF THIS IS COM 2

TESTING COM 2 PORT

The RTS and DTR lights should be flashing.
If they are not FLASHING, you are not
connected to COM 2.

Press any key to continue.

Did RTS and DTR FLASH this time? (Y/N)

YOU ARE NOT ATTACHED TO COM 2

Press any key to continue.

1 = TEST CUSTOMER'S COMPUTER

(Do not plug SCHEDULER in)

2 = IMPORT A TEST FILE

(Plug in the SCHEDULER first)

Q = QUIT

MENU of Programs for the SCHEDULER
SCHEDULER Version 4.0

If you have any difficulty with these programs, phone 1-800-356-0458

6180 COCHRAN ROAD
SOLON,OHIO
1-216-349-6881

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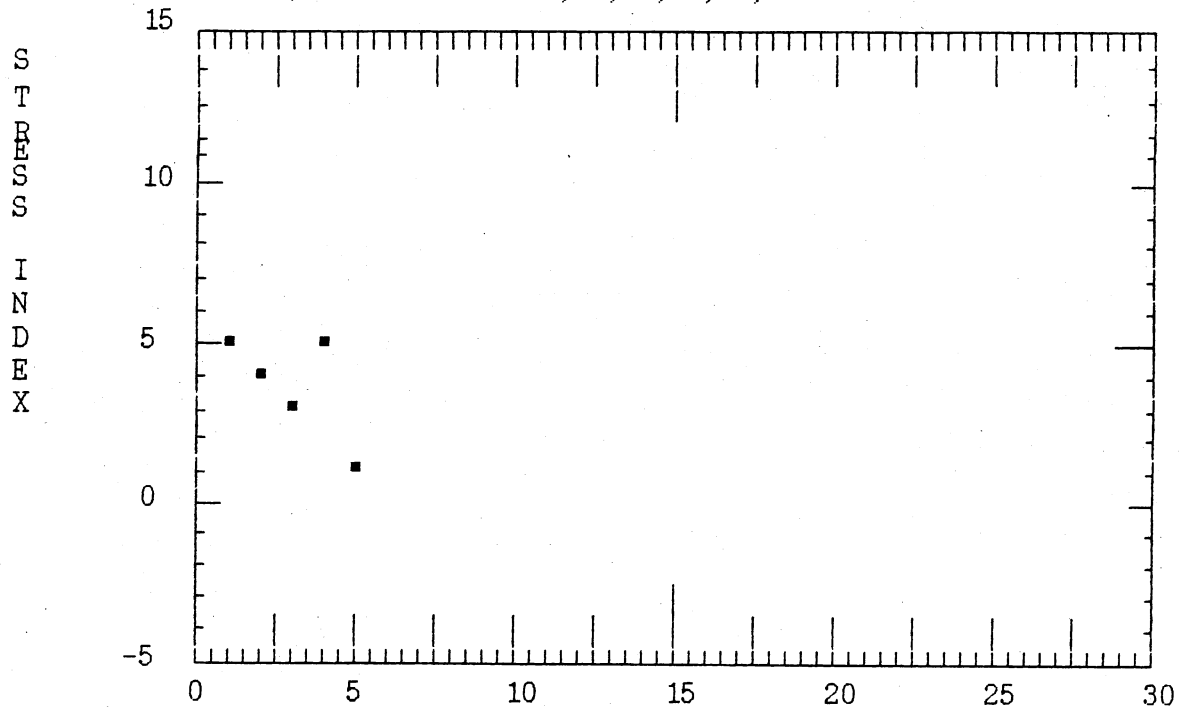
STANDARD OIL ENGINEERED MATERIALS CO.

No	Name	Function of the Programs--PRODUCTION Models Only
1	IMPORT	DOWN-LOAD TODAYS DATA TO A TEMPORARY FILE
2	PRINT	PRINT TODAY'S DATA TO THE SCREEN OR A PRINTER
		ANALYSIS OPTIONS
3	TODAY	GRAPH TODAY'S DATA
4	PATTERNS	PATTERNS OF TODAY'S DATA
5	HISTG	GRAPH HISTORICAL FILE
6	HISTP	PRINT HISTORICAL FILE
U	UTIL	UTILITIES

CLEVELAND--APRIL 22, 1989 FIELDS 1, 2, 3, 4, 5,



FIELD DATA FOR 04/22/89

FIELD	CROP	STAGE	TIME	AVERAGES CROP	AIR	RH	SUN	STRESS INDEX	SAMPLES TAKEN
01	ALFALFA		14:00	+088.0	+089.0	40	97	+05.3	09
02	WHEAT	01	14:10	+083.0	+085.4	29	90	+03.9	07
03	WHEAT		15:00	+084.0	+088.0	26	87	+03.4	06
04	ALFALFA		14:30	+090.5	+091.1	23	88	+05.3	07
05	WHEAT	01	12:15	+080.9	+090.2	22	89	+01.1	08
06	ALFALFA		13:20	+088.3	+098.1	22	94	+01.4	10

PRINT AGAIN? (Y/N)

CLEVELAND--APRIL 22, 1989 FIELDS 1, 2, 3, 4,

PATTERN OF CANOPY TEMPERATURES

9the average canopy temp. has been subtracted)

FIELDS	1- 5	2	-3	-2	4	****
FIELDS	6-10	****	****	****	****	****
FIELDS	11-15	****	****	****	****	****
FIELDS	16-20	****	****	****	****	****
FIELDS	21-25	****	****	****	****	****
FIELDS	26-30	****	****	****	****	****

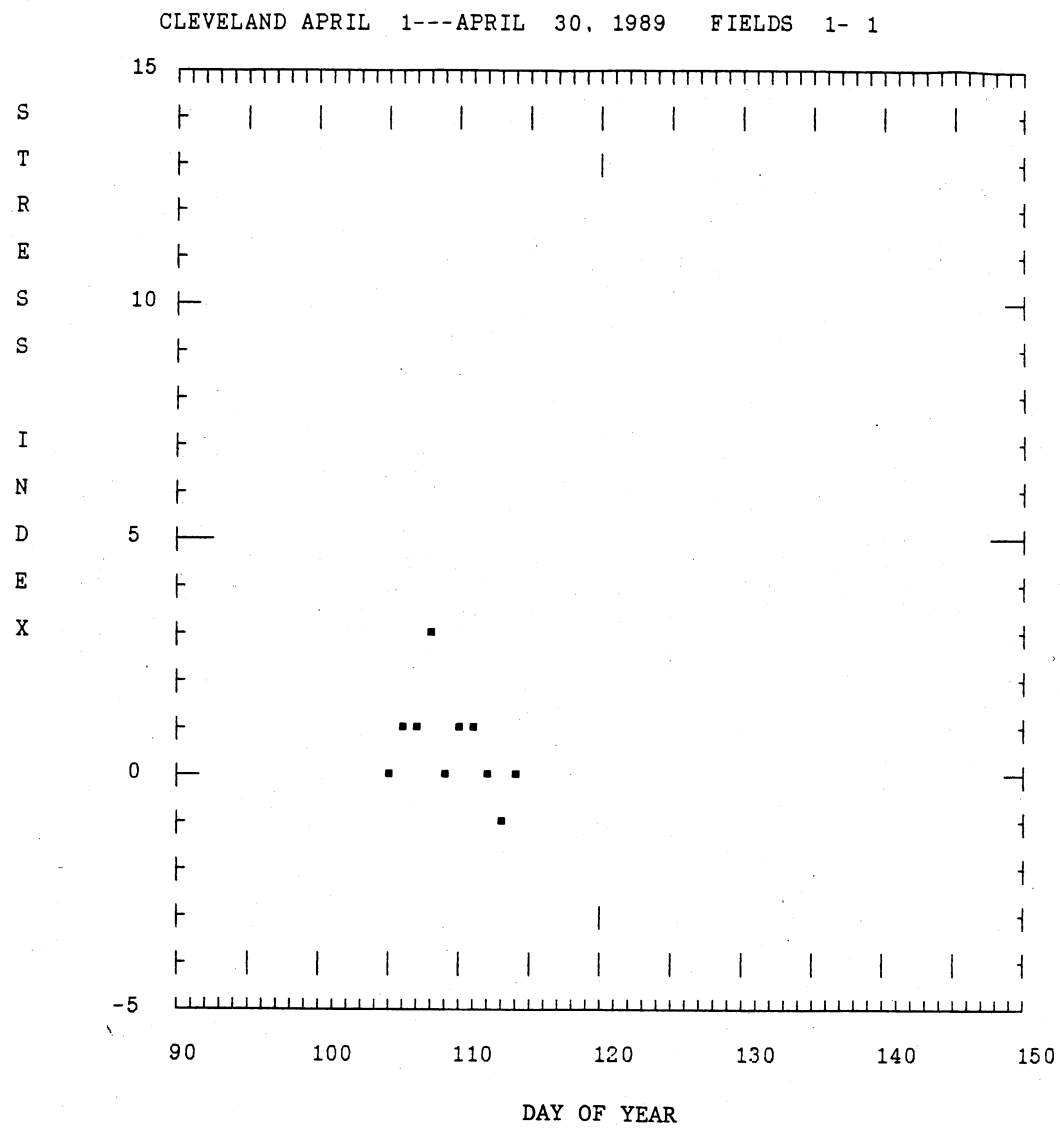
AVERAGES

CROP TEMP = 86
AIR TEMP = 88
REL. HUM. = 30
SUNLIGHT = 90
INDEX = 4.5

PATTERN OF RELATIVE STRESS INDEX VALUES

(The overall index average has been subtracted)

FIELDS	1- 5	1	-1	-1	1	****
FIELDS	6-10	****	****	****	****	****
FIELDS	11-15	****	****	****	****	****
FIELDS	16-20	****	****	****	****	****
FIELDS	21-25	****	****	****	****	****
FIELDS	26-30	****	****	****	****	****


CLEVELAND APRIL 1---APRIL 30, 1989 FIELDS 1- 1
STRESS INDEX
15
10
5
0
-5
90
100
110
120
130
140
150
DAY OF YEAR

PREPARE THE SCHEDULER TO 'PRINT'

MAKE SURE THE SCHEDULER CONFIGURATION IS :

BAUD RATE	1200
CHAR. SIZE	8
STOP BITS	2
PARITY	NONE
XON/XOFF	DISABLED

READY TO RECEIVE SCHEDULER DATA (PRESS 'Q' TO RETURN)

UTILITY OPTIONS
F = GIVE A NAME TO EACH FIELD NUMBER
P = PRINT LIST OF FIELD NUMBER/NAMES
S = PROGRAM SET-UP OPTIONS
L = LOAD DEMONSTRATION DATA
T = TEST CUSTOMER'S COMPUTER D = FILES ON CURRENT DIRECTORY ALT-E = EXPORT DATA TO AN ASCII FILE
ALT-I = IMPORT EXTERNAL DATA FILES
ALT-R = RESET HISTORICAL DATA FILE
E = CHECK FOR PROGRAM ERRORS
Q = RETURN TO MAIN MENU

Current Field Names:

# 1, JOHNSON RANCH--ALFALFA	# 16,''
# 2, BARTLETT FARM--WHEAT	# 17,''
# 3, KEN FREEMAN'S WHEAT	# 18,''
# 4, RICK MASON-- ALFALFA	# 19,''
# 5, TOM JACKSON-- WHEAT	# 20,''
# 6, BRIAN HARPER--ALFALFA	# 21,''
# 7, ''	# 22,''
# 8, ''	# 23,''
# 9, ''	# 24,''
# 10,''	# 25,''
# 11,''	# 26,''
# 12,''	# 27,''
# 13,''	# 28,''
# 14,''	# 29,''
# 15,''	# 30,''

Enter ⏎ to leave unchanged Type a new NAME and press ⏎ to change.
*** Make these changes permanent (y/n)?

Status according to RAM

Total Memory	512 Kbytes	Disk drives	2
I/O Memory	0 Kbytes	Parallel ports	0
Sys Brd Mem	64 Kbytes	Serial ports	1
Video def	80x25 Color card	Game adapter	YES
Unused Memory 340	Kbytes		

ACCORDING TO RAM, YOU HAVE 1 RS-232 PORT.

press any key to continue ('Q' to quit)

```
THESE ARE THE ERROR CODE TRANSLATIONS      (your last error code was  0  )
 1--NEXT without FOR                      (on line  0  )
 3--RETURN without GOSUB
 4--Out of DATA
 5--Illegal function call
 6--Overflow
 7--Out of memory
 8--Undefined line number
 9--Subscript out of range
10--Duplicate definition
11--Division by zero
12--Illegal direct
13--type mismatch
14--Out of string space
15--String too long
16--String formula too complex
17--Can't continue
18--Undefined user function
19--No RESUME

press any key to continue
```

```
(your last error code was  0  on line  0  )
20--RESUME without error
21--Unprintable error
22--Missing operand
23--Line buffer overflow
24--Device timeout
25--Device fault
26--FOR without NEXT
27--Out of paper
29--WHILE without WEND
30--WEND without WHILE
50--FIELD overflow
51--internal error
52--bad file number
53--File not found
54--Bad file mode
55--File already open
57--Device I/O error
58--File already exists
61--Disk Full

press any key to continue
```

```
(your last error code was  0  on line  0  )
62--input past end
63--Bad record number
64--Bad file name
66--Direct statement in file
67--too many files
68--Device unavailable
69--Communication buffer overflow
70--Disk Write Protect
71--Disk not ready
72--Disk media error
73--Advanced feature
74--Rename across disks
75--Path/File access error
76--Path not found

press any key to continue
```

Status according to RAM

Total Memory	640 Kbytes	Disk drives	2
I/O Memory	2 Kbytes	Parallel ports	1
Sys Brd Mem	64 Kbytes	Serial ports	2
Video def	80x25 Color card	Game adapter	YES
Unused Memory 404	Kbytes		

ACCORDING TO RAM, YOU HAVE 2 RS-232 PORTS.

press any key to continue ('Q' to quit)

SCHEDULER SUPPORT SOFTWARE

R&D MODEL

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SENSOR TECHNOLOGY
CARBORUNDUM
6180 COCHRAN ROAD
SOLON, OHIO 44139

216-349-6881
or
1-800-356-0458

QUICK START

> Check your hard-disk to make sure there is sufficient space to store the program by typing :

```
C:      then press  [ENTER]
DIR                 [ENTER]
```

You should have at least 180,000 bytes free.

> Your computer should have at least 256 K of RAM.

> Create a sub-directory for the programs by typing :

```
C :     then press [ENTER]
CD\                [ENTER]
MKDIR  R&D         [ENTER]
CD\R&D
COPY A:*.*   C:*.*
```

note : you do not need to use the name R&D for your sub-directory. You can use any name you like. Just substitute the name you choose for R&D wherever you see it in these instructions

> Running the program :

```
CD\R&D          [ENTER]
MENU             [ENTER]
```

CHAPTER ONE

PROGRAM SET-UP

> Start the progaram with these instructions :

```
C :       [ENTER]
CD\R&D  [ENTER]
MENU      [ENTER]
```

note, if you have stored the programs in a different sub-directory, then substitute the name of that sub-directory for R&D.

> Press "U" on the keyboard to select the Utilities menu
PRESS "T" on the keyboard to test your computer
(this test is usually done by your dealer. It determines if you have the necessary hardware to allow your computer to "talk" to the Scheduler and the proper "name" of this hardware (the proper name is either COM1 or COM2).
When you are done with this test, you will be returned to the Utilities menu.

Press "S" on the keyboard to set-up program parameters.
You will be asked to answer several questions :

- The name of the farm. The name you enter here will appear on all future reports.
- The drive the programs are stored on. Most hard drives are labeled "c" (but may have other letters. Floppy disk drives are labeled "A" or "B".
- The drive you want to store data on. Usually, the programs and data are stored on the same drive, but this is not necessary.
- Is the temperature in F or C ? Most people (in the U.S.) have their Scheduler's programmed to display temperatures in farenheit (F), but some people like to use the centigrade (C) scale.
- Is the communication port COM1 or COM2. The answer to this questions depends on the results of from the "Test" utility.
- The name of the crops in your Scheduler. This list will be used to help you in preparing reports.
- The "name" of the Scheduler field. You can assign a name (up to 28 characters long) to each Scheduler field number. The list can be modified at any time.

when you are finished with the SETUP questions, press "Q" to return to the MAIN MENU.

CHAPTER TWO

PROGRAM FEATURES

2.1 System requirements

The Scheduler analysis software was designed to run on any IBM compatible personal computer.

You may operate the program directly from the floppy disk or you may run the program from the hard-drive. Your hard disk must have at least 180,000 bytes of available storage space; one serial port;one floppy drive; 256 Kb RAM; a monochrome or color monitor (the program does not use colors); DOS 3.0 or higher (DOS 2.0 should work, but there is a potential that it won't. Try it and see).

Communications ports on some computers will occaisionally generate random characters, especially line feeds and carriage returns. This means that the file your computer stores may not be exactly like the file the Scheduler sent. The IMPORT option in the software has been designed to compensate for these occurences. If you have any difficulty importing a Scheduler file, please contact us for a solution.

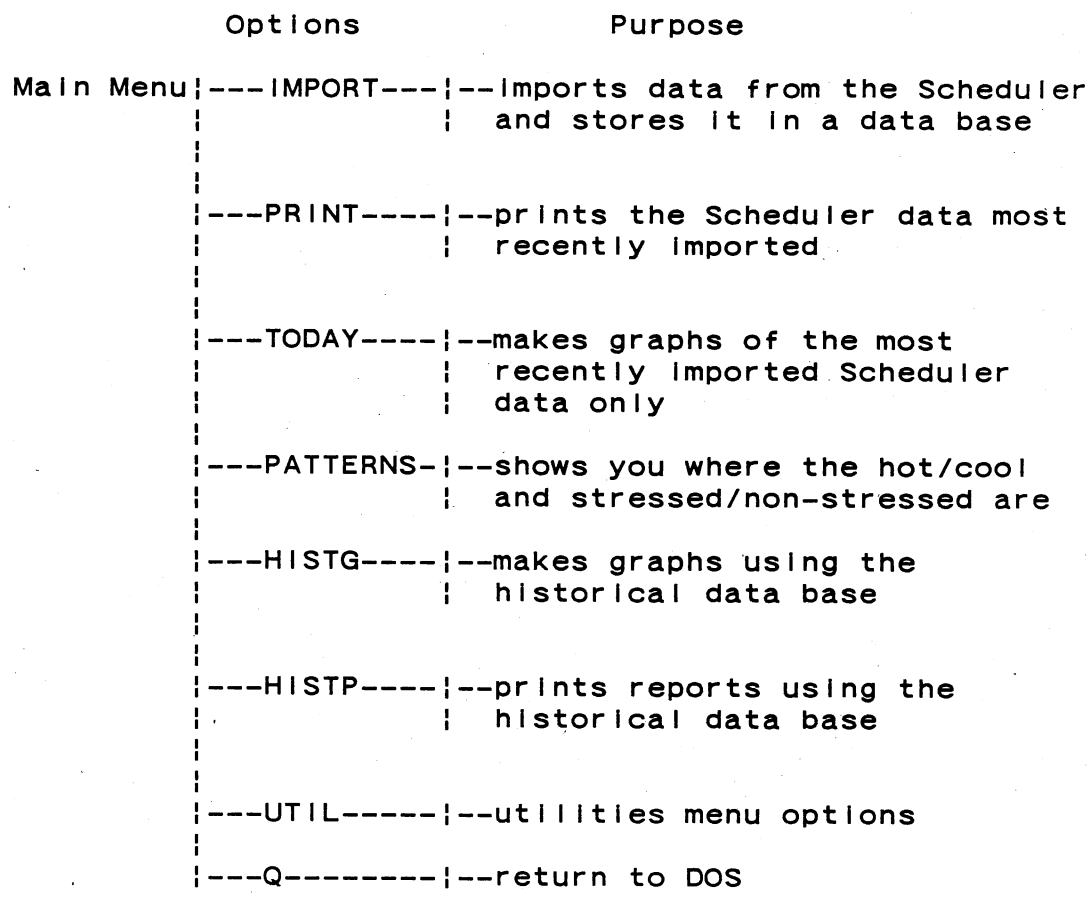
The Scheduler analysis software is provided on 3.5 " and 5.25" floppy disks.

2.2 Menus

There is one MAIN menu and one UTILITIES menu. From either menu, you simply press the indicated letters or numbers to select the option you want.

	Option	Purpose
Utilities Menu	----F----	give a name to any of the 240 fields
	----S----	change the SET-UP options
	----L----	load demonstration data.
	----T----	test customers computer. This option identifies if the computer has essential hardware and the proper name (COM1 or COM2) for the serial port.
	----D----	display the directory of files on the current drive
	ALT-E---	exports user selected data from the historical data base to an ASCII file
	ALT-I---	imports Scheduler data from an existing file and adds it to the the historical data base
	ALT-R---	erases the contents of the historical data base
	----E----	identifies the type and source of any hardware/software errors
	----Q----	returns to main menu

2.3 Program Structure



CHAPTER THREE

MAIN PROGRAM

SELECTION OPTIONS

Except for the IMPORT option, all the MAIN menu options ask you to select the data which is to be used. The selection options are :

- minimum - maximum field number to use
- random selection of field numbers
- crop type

You may select any combination of fields or range of fields for any of the 240 fields contained in the R&D model.

With these options, you should be able to tailor your reports to your specific needs.

3.1 IMPORT

The import option allows you to import files from the Scheduler and store the information in a permant data base.

3.2 PRINT

This option allows you to print (to the screen or a printer) the most recently imported Scheduler file exactly as it appears in your computer. This provides you with a hard-copy of the data you collected today.

Note: The "most recently imported" file is not up-dated until you import another file. This means you always have access to the data from the "last time".

3.3 TODAY

This option allows you to make graphs of the most recently imported data. You may select the data you want to graph by field number (any 1 or any combination of fields) or by crop name. For example, you may want to graph data which comes from fields 1,11,127, and 219 and exclude all the rest. Or you may want to graph only alfalfa data. If you want to graph the data from fields 41-139 (or any other range of fields), you can do that too.

You may choose from two horizontal axis options:

- time of day
- field number

You may select from 6 vertical axis options:

- crop temperature
- air temperature
- relative humidity
- sunlight reading
- stress index
- crop-air temperature difference

3.4 PATTERNS

The pattern report takes a little getting used to. After selecting which data to use, you will see a lot of little boxes. The boxes represent a single field. They will look something like this :

1-10 **** **** **** **** **** **** **** **** **** ****

These ten boxes represent (from left to right) fields 1,2,3,4,5,6,7,8,9, and 10. Again :

11-20 **** **** **** **** **** **** **** **** **** ****

These boxes represent fields 11 through 20.

If you see a ****, it means that there was no data collected on that field or that you did not select that field for this particular report.

If you a number in place of the ****, then it means that data was collected on this field today and that you selected that field for this report.

With this report, you can quickly determine how uniform crop temperature is on the fields you selected.

USING THE PATTERN REPORT

The pattern report is very powerful once you get used to it. Suppose it looks like this:

```
FIELDS  1-10    **** **** **** **** **** **** **** **** **** ****
FIELDS 11-20     1    1   -1    0   -1    1    0    0    1    3 SMITH
FIELDS 21-30    **** **** **** **** **** **** **** **** **** ****
FIELDS 31-40    **** **** **** **** **** **** **** **** **** ****
FIELDS 41-50    **** **** **** **** **** **** **** **** **** ****
FIELDS 51-60    **** **** **** **** **** **** **** **** **** **** 7/24/
FIELDS 61-70    **** **** **** **** **** **** **** **** **** **** 1989
FIELDS 71-80    **** **** **** **** **** **** **** **** **** ****
FIELDS 81-90    **** **** **** **** **** **** **** **** **** ****
FIELDS 91-100   **** **** **** **** **** **** **** **** **** ****
FIELDS 101-110  **** **** **** **** **** **** **** **** **** ****
FIELDS 111-120  **** **** **** **** **** **** **** **** **** ****
FIELDS 121-130   **** ****  **** ****  **** ****  **** ****  ****  ****RES
FIELDS 131-140  **** **** **** **** **** **** **** **** **** ****
FIELDS 141-150  **** **** **** **** **** **** **** **** **** ****TC=85+/-
FIELDS 151-160  **** **** **** **** **** **** **** **** **** ****TA=88+/-
FIELDS 161-170  **** **** **** **** **** **** **** **** **** ****RH=45+/-
FIELDS 171-180  **** **** **** **** **** **** **** **** **** ****SUN=94+/-
FIELDS 181-190  **** **** **** **** **** **** **** **** **** ****SI=2+/- 1
FIELDS 191-200  **** **** **** **** **** **** **** **** **** ****
FIELDS 201-210  **** **** **** **** **** **** **** **** **** ****
FIELDS 211-220  **** **** **** **** **** **** **** **** **** ****
FIELDS 221-230  **** **** **** **** **** **** **** **** **** ****
FIELDS 231-240  **** **** **** **** **** **** **** **** **** ****
```

This report means that you selected the data from 10 fields to use (Fields 11-20). The average crop temperature, air temperature, relative humidity, sunlight, and index on all 10 of these fields are given to the right. The standard deviation of each of the measurements is also given. This standard deviation is based on the number of fields selected for the report.

A "0" means that the crop temperature on that field was equal to the average crop temperature for the five fields (in this case , 85 degrees). A -1 means that the average crop temperature was 1 degree below the average temperature. For this example, field 13 is 1 degree below the average , or 84 degrees. Field 20 has a 3 in its box. This means that the crop temperature is 3 degrees above average here (or 88 degrees).

Suppose you had selected only those fields containing cotton. If all the fields have uniform temperatures, their boxes would contain on 0's, or 1's or -1's. But a field which is unusually hot, compared to the average, immediately shows up as a large positive number. Also, a field which is unusually cool will show up as a large negative number. This report quickly alerts you to unusual areas.

3.5 HISTG

This option allows you to make plots of all the data you have imported into the Scheduler. When you select this option, you will be asked to select the data to use according to :

- field number (or range)
- crop name
- starting date
- ending date

The vertical axis options are the same as for the TODAY graphs :

Crop Temperature
Air temperature
Relative Humidity
Sun-light reading
Stress Index
Crop-Air temperature difference

The horizontal axis options are :

- time of day
- field number
- date

You can create graphs which will show you trends for 1 field, any combination of fields or any crop on any of the 240 fields measured by the R&D unit.

Your most complete reports can be made when you import your data every day.

3.6 HISTP

This option acts the same way as the HISTG option except that a print-out is generated (on the screen or on a printer) instead of a graph. This option allows you to create a permanent hard-copy of any records you feel are important. This is a convenient way to produce annual reports. For example, if you wanted to print-out the data for just field number 23, you could decide to print out "by field interval" and select 23 and the upper and lower limit. The result would be a printout of all the data on only field 23 for the entire year.

Reminder, the names of all 240 fields can be reviewed simply by using the PgUp and PgDn keys.

CHAPTER FOUR

UTILITIES MENU

4.1 "F"

This option allows you to assign/edit your own names to each Scheduler field number. You may change any name at any time (without affecting the other names) or you may erase the names and start over again. The names you put here will be shown to you at appropriate times throughout the program, so try to select names which will help you when it comes time to making out your reports.

4.2 "S"

This option allows you to reset the program parameters (see chapter one). Any permanent data you have already stored is not affected.

4.3 "L"

This loads some demonstration data. The purpose of this file is to simply demonstrate the various graphs and reports without the need to actually collect and IMPORT Scheduler data. The data has been artificially created to demonstrate the software, there is no useful crop information in it.

4.4 "T"

This is for testing your computer. Normally this test should be conducted by your dealer or by someone who is familiar with the operation of computers. The purpose of this test is to determine if the computer has at least 1 serial port (so the Scheduler can "talk" to the computer) and to identify the technical name of this port "COM1" or "COM2". This option also allows you to import a test Scheduler file to make sure the serial port works properly.

4.5 "D"

This shows you a directory listing of all files on your current drive. When you begin importing/exporting files, you may need to refer to a directory listing of file names to avoid confusion.

4.6 ALT-E

This option is used to export data from your permanent data base to an ASCII file. You will be asked to select the data to be exported according to :

- date collected
- field number (any 1 field, or any combination) or crop name

You will also be asked for the name of the external file. The name you give it must be a correct DOS name. Refer to your DOS manual for details on how to give a correct name.

Correct DOS names follow this format :

#:*.@

The # represents the drive you want to store this data on (A, B, C, etc.)

The * is any name (eight-letters maximum) you want to make up (almost anything will work).

The @ is any name (three letters maximum) you want to make up. Any 3 letters are o.k. The combination "DAT" is often used for data.

For example, to EXPORT data to a file called "TESTING" to the A: drive, one correct DOS name would be :

A:TESTING.DAT

4.7 ALT-I

This option allows you to import existing Scheduler data and store it in your permanent data base.

4.8 ALT-R

The purpose of this option is to allow you to erase the contents of your permanent data base. You will be given two warnings to respond to before the file is erased.

4.9 E

Occaisionally something goes wrong, but nobody knows what. Unless the error is "fatal" (the program stops working), after an error occurs, select "U" for the Utilities menu and "E". You will be given information which shows you what type of error occured and where in the program it happened. Also given will be a list of definitions to describe to you what happened. Always check this when things don't go right. Its the fast way to find out you've overlooked something (like putting a disk in the drive). It can also help us in de-bugging the program.

CHAPTER 5

TROUBLE SHOOTING

5.1 Assistance

You can phone us at 1-800-356-0458 or at 1-216-349-6881 during working hours.

Most errors can be identified using the "E" option from the Utilities menu of the program. Sofware "bugs" and most common user errors can be isolated this way.

5.2 Other Errors

SCHEDULER DOESN'T SEND DATA

You've started the IMPORT option and the computer screen says it is ready to receive data, and you've pressed all the PRINT buttons on the SCHEDULER. The Scheduler screen says "SENDING DATA" but nothing happens on the screen. This can occaisionally occur with any computer. If this happens, just turn the Scheduler off, and EXIT the program. Then re-start the program and try IMPORT again.

If this fails to make the Scheduler send its data, you could have SET-UP the program wrong. This usually happens when a customer has two serial ports (COM1 and COM2) on his computer. Try the SET-UP routine again. Try both the COM1 and COM2 settings.

THE GRAPHS THAT ARE PRINTED DON'T LOOK LIKE THE GRAPHS ON THE SCREEN.

This is not a problem with your computer, the Scheduler, or the program. The problem is with the printer. Most printers have several optional features which are not always "enabled". One of these options allows a printer to receive graphics characters from a computer. Setting these options is usually just a matter of flipping a switch somewhere. The printer manual will need to be checked. If you have questions about this one, it is best to first check with the vendor who sold you the printer.

SCHEDULER TUTORIAL

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THE PLANT IS THE KEY

The ideal moisture stress reading is based on a direct plant measurement instead of a soil or atmospheric measurement (Clark, 1973). Think about this. Agriculture is concerned primarily with growing plants. Does it make sense to ignore information which comes directly from the plant? Of course not. It is important to understand that the plant is the best guide to its condition. Suppose you went to the doctor because you were feeling bad. Then, the doctor phones up the National Weather Bureau to find out the weather forecast. He then says, "Yup, I think you're probably going stay sick for about 3 or 4 more days." There's no doubt the weather is an important factor in making people sick, but wouldn't you feel just a little more confident in the doctor's diagnosis if he said "stick out your tongue and say AAAAH".

The main reason farms exist is to produce plants and plant products. A manager has two choices:

- Measure the environment (soil, weather) and guess the condition of the plant.
- Directly measure plant condition as well as the environment.

WHY MAKE GUESSES ABOUT PLANT CONDITION WHEN IT IS SO EASY TO MAKE DIRECT MEASUREMENTS?

A SIMPLE PRINCIPLE

CWSI (crop water stress index) is based on a simple principle. Any surface which is evaporating water at a high rate will be cooler than a similar surface that is not evaporating water as fast. You have probably experienced this principle many times. Recall a summer day at the beach. Before diving into the water, the summer sun made your skin feel warm. After you emerged from the water, you felt much cooler. Why? Simple. Your skin was evaporating water much faster when it was wet than when it was dry.

In a similar fashion, a leaf that is supplied with adequate water (non-stressed) will evaporate water faster than a leaf that has inadequate water (stressed). The result will be a difference in temperature between the non-stressed and the stressed leaves.

Back to the beach. If you felt too hot at the beach, you had two options to cool down, first, you could jump into the water, second, you could just walk into the shade. Isn't it amazing how much cooler you feel standing in the shade than when standing in the sun?

Plants react much the same way. Whenever a cloud moves in front of the sun, their temperature will also decrease. This means that whenever we want to compare stressed and non-stressed plant temperatures, we must be careful to make that comparison under the same sunlight conditions. It makes no sense to compare the temperature of a leaf in the shade with a sunlit leaf. The sunlit leaf will always be hotter. (Have you ever felt hotter in the shade than in the sun?)

CROP TEMPERATURE RESEARCH

Many scientists have studied plant temperatures during the last 150 years. A few were able to capture and understand the relationship between the plant's temperature and its overall health. Accurate temperature measuring devices were needed to advance the practical use of plant temperature. Only during the last 10 years were the first reliable hand-held infrared thermometers manufactured and commercially available to advance the use of this technology. Following is a summary of the major facts which have been reported.

1875 -- Thin leaves are cooler than thick leaves.
1905 -- Sudden increases in wind speed causes a decrease in plant temperature.
1915 -- The leaves of evergreens are much hotter than the air during winter (that's how they survive and photosynthesize).
1923 -- USDA researchers in Arizona showed that healthy leaves of various crop plants are cooler than the air during mid-day.
1929 -- The USDA confirmed that healthy cotton leaves can be 8 F or more cooler than the air.
1938 -- Garden plants can be as much as 14oF below air temperature.
1052 -- The temperature of tomato and potato leaves are nearly the same.
1962 -- A scientist developed equations which showed that if a leaf remains motionless while the wind blows, its temperature is controlled by the windspeed, but if the leaf flaps, water evaporation controls leaf temperature.
1966 -- Infrared thermometers were first used to measure leaf and canopy temperature. The importance of solar radiation and time of day was emphasized.
1971 -- Leaf water content is correlated with leaf temperatures and relative humidity.
1973 -- Leaf water potential, stomatal resistance and leaf-air temperature differences are all correlated.
1973 -- A USDA scientist suggested using leaf-air temperature differences to schedule irrigations.
1981 -- USDA scientists developed the crop water stress index (CWSI).

In 1984, Standard Oil Engineered Materials Company (The Carborundum Company) conducted the first large scale field test of the CWSI concept. Prior to that time all the research had been conducted on small plots. Standard Oil Engineered Materials has been the driving force behind the technology transfer of CWSI from the theoretical domain of research scientists to the practical world of growers.

1984 -- First field test of CWSI concept.
1985 -- Multi-state field tests of CWSI.
1986-1988 -- Field tests continue. Simultaneously, the marketing/commercialization of the Scheduler was begun.

Between 1978 and 1988, the literature has exploded with information which demonstrates that canopy temperatures can be used to schedule irrigation and monitor crop condition on a wide variety of crops.

Standard Oil Engineered Materials has collected CWSI information from over 125 separate locations (experiments and grower fields). No other infrared thermometer company has been involved in CWSI research of this magnitude.

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- Non-stressed leaves are usually cooler than the air.
- Plant temperature is related to plant health. A plant that is "stressed" will (when the sun is shining brightly) will be hotter than a healthy "over-stressed" plant.

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Do not be afraid to ask questions. Once you master the basics, you will start to feel comfortable with the Scheduler.

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The Scheduler is based on very sound physical and scientific principles. Those who learn to use it first will be the furthest ahead.

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- Plant temperatures can be used to indicate plant stress.
- Higher than normal plant temperatures results in yield and quality losses.
- The hotter a plant is (relative to air temperature), the lower its transpiration rate.
- In the field environment, plant temperature variability is a sign that stress has just begun.

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- The information you need to know to calculate an index is simple. Every one is familiar with air temperature and relative humidity. Plant temperature is the only new piece of information.
- The math is very simple

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Points to Remember

- Clear skies and time of day are critical considerations.
- Negative index values are normal.
- Negative index values indicate no stress.
- Mistakes can artificially create negative index values.
  - Crop is wet
  - Wrong time of day
  - Poor aiming technique
  - Unusually cool air
  - Sensor gun was too hot

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Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour. Be consistent on the time of day you make measurements.

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QUOTES FROM RESEARCHERS

The following statements summarize the conclusions of agricultural scientists concerning plant temperatures during the period 1929 - 1988. There is little room for doubt that leaf temperatures are considered very important.

"The facts suggest that the differences in yields are associated with the observed differences in their leaf temperatures." (Eaton and Belden, 1929).

"...transpiration invariably tends to lower the temperature of the transpiring leaf...." (Curtis, 1936).

"Leaf temperature relative to air temperature can be predicted..." (Waggoner and Shaw, 1952).

"Thus a sensitive measurement of the temperature difference between plant samples may provide an indication of transpiration differences." (Tanner, 1963).

"The temperature differences between well-watered and stressed crops should indicate a relative need for irrigation. Within large irrigation projects it should be possible to identify fields needing irrigation from crop canopy temperature information. Within individual fields plants in areas not irrigated adequately should stress sooner and have a higher canopy temperature than the nonstressed plants in well-watered surrounding areas." (Bartholic et al., 1972).

"On a given day, relative leaf water content and leaf temperature were highly correlated." (Carlson et al., 1972).

"Field studies at this laboratory have shown Tc-Ta to be a sensitive guide to changes in stomatal aperture, as measured by leaf resistance." (Ehrler, 1973).

"...measurement of Tc-Ta still appears adequate for assessing soil water status effects on crop vigor and signalling needed irrigation ..." (Idso and Ehrler, 1976).

"The results indicate that the temperature differences between the stressed and the unstressed plants arises primarily from differences in transpiration. It is further suggested that after proper calibration, plant temperature promises to be a reliable index for identifying crop water deficits and for optimizing irrigation scheduling." (Sandhu and Horton, 1978).

"The results of this experiment suggest that knowledge of leaf and air temperatures, which are relatively easy and inexpensive to determine, can be useful in assessing the water status of corn and sorghum." (Sumayao et al., 1980).

"The results demonstrate the ability of surface temperature measurement by means of infrared thermometry to rapidly assess large areas of cropped land for plant water potential depressions arising from shortages of soil moisture." (Idso et al., 1981)

"We conclude that canopy temperature variability can be used to signal the onset of plant water stress...." (Clawson and Blad, 1981).

"...canopy temperature data can be used to track crop water stress and the effect of stress on yield...soil factors indicate when plants may be stressed, plant factors indicate when they are stressed. Plant factors, such as water potential, are point measurements that require numerous samples to characterize a field. Canopy temperature measurements can minimize this problem." (Jackson, 1982).

"...linear regression analysis indicate close correlation between water stress index...and water potential..." (Tormann, 1986)

"The Infrared Thermometry device as represented by the "Scheduler" ...is a very sensitive and yet practical means of determining the water stress status of a crop such as vines. The neutron probe while quite accurate in its evaluation of soil moisture content did not provide any measurement of stress...The IRT device is as sensitive to plant stress as the porometer while more simple to operate and maintain than the other devices discussed above...If a known, unstressed vine is used as a reference and the indexes for the vines in question for that date are compared with the reference vine then the IRT method can be used very well for stress management." (Krauter, 1988).

DEFINITION OF THE INDEX

Think of the stress index as a percentage. You use percentages all the time. For example, sales commissions are often expressed as a percentage. A salesman wants this percentage to be as high as possible. But, what what kind of stress index reading should you want? Let's compare the index to a sales commission.

$$\text{percent profit} = \frac{[\text{sales commission}]}{[\text{retail price}]} \times 100$$

All your percentages are scaled between 0 and 100 % because you multiply by 100.
similarly,

$$\text{stress index} = \frac{[\text{ actual stress }]}{[\text{potential stress}]} \times 10$$

Actual stress is based on actual plant temperature.
Potential stress is based on how hot a plant could get if it had no available soil moisture.

All the stress index percentages are scaled between 0 and 10 because we multiply by 10.
If we could estimate actual and potential stress perfectly (we can't) then the following chart would be true:

Index		stress interpretation	evaporation rate (ET) interpretation
0	=	no stress detected	100 % of maximum ET
1	=	10 % of potential stress	90 % of maximum ET
2	=	20 % of potential stress	80 % of maximum ET
3	=	30 % of potential stress	70 % of maximum ET
4	=	40 % of potential stress	60 % of maximum ET
5	=	50 % of potential stress	50 % of maximum ET
6	=	60 % of potential stress	40 % of maximum ET
7	=	70 % of potential stress	30 % of maximum ET
8	=	80 % of potential stress	20 % of maximum ET
9	=	90 % of potential stress	10 % of maximum ET
10	=	100 % of potential stress	0 % of maximum ET

In reality, the index can be less than 0 or greater than 10. This is simply caused by the statistical process used to estimate actual and potential stress. In practice, we do not estimate actual ET rates. We base decisions on whether or not to irrigate (or whether stress is present) on how much the index has changed over time , how uniform index readings are and field experience.

CALCULCATING THE INDEX

At this point, you're probably thinking "O.K., I can understand that much. But how do you measure 'actual stress' and 'possible stress.'" It's not really very complicated. In fact, it's really very easy. You can calculate an index without using a computer, equations or anything fancy. All you need is some information. What information? All you need to know is:

- air temperature
- relative humidity
- plant temperature

The next step can be done by almost anyone: subtract air temperature from plant temperature. For example, if air temperature is 100o F and plant temperature is 95o F, then 95 - 100 = - 5. The plant canopy is 5 degrees cooler than the air.

Let's do that again, but this time use a simple equation:

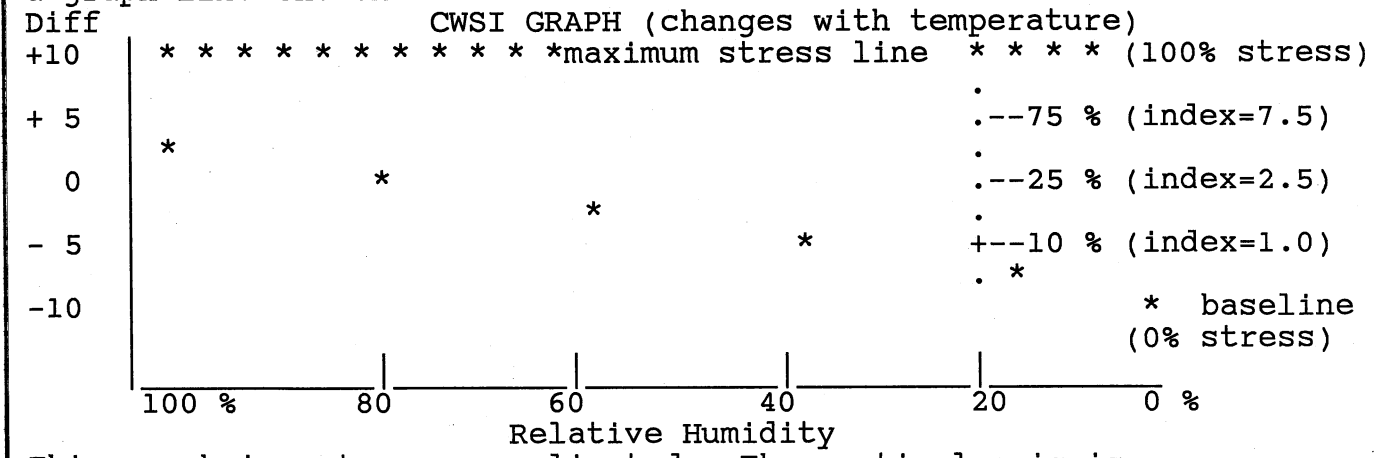
Diff = Tc - Ta — Tc is just the plant temperature (or temperature/air) and Ta is just the air temperature. Let's put the numbers in.

Diff = 95- 100

Diff = -5 — Now we have a name for the number. The name is Diff, which stands for "the difference in temperature between a plant and the air temperature", (or the delta temperature

That's it. The information isn't mysterious. It's very simple. The math isn't hard at all.

Now that you know the plants are 5 degrees cooler than the air, and suppose the relative humidity is 20%, just look at a graph like the one below:



This graph is not very complicated. The vertical axis is where we find the value of Diff (remember that subtraction we had to make ?). The horizontal axis is where we look up the relative humidity.

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Please note, the horizontal axis in the real index calculation is not strictly determined by the relative humidity but rather a combination of humidity and temperature called the Vapor Pressure Deficit (VPD).
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ORIGIN OF A BASELINE

First, we use the Scheduler on healthy and stressed areas of a particular crop for as much of the season as we can. If we can collect data for more than one season, or in more than one location, so much the better. Two mathematical equations are then developed which effectively summarizes all this information, so that we can use it in a computer. One equation is called a baseline. The other equation is called the maximum stress line. The baseline represents 0% stress (or an index of 0). The maximum stress line represents 100% stress (or an index of 10). If the index was perfect, the index would never be less than 0 or greater than 10. In practice, the index will often be less than 0 and can exceed 10.

Equations have been developed for a number of crops, including:

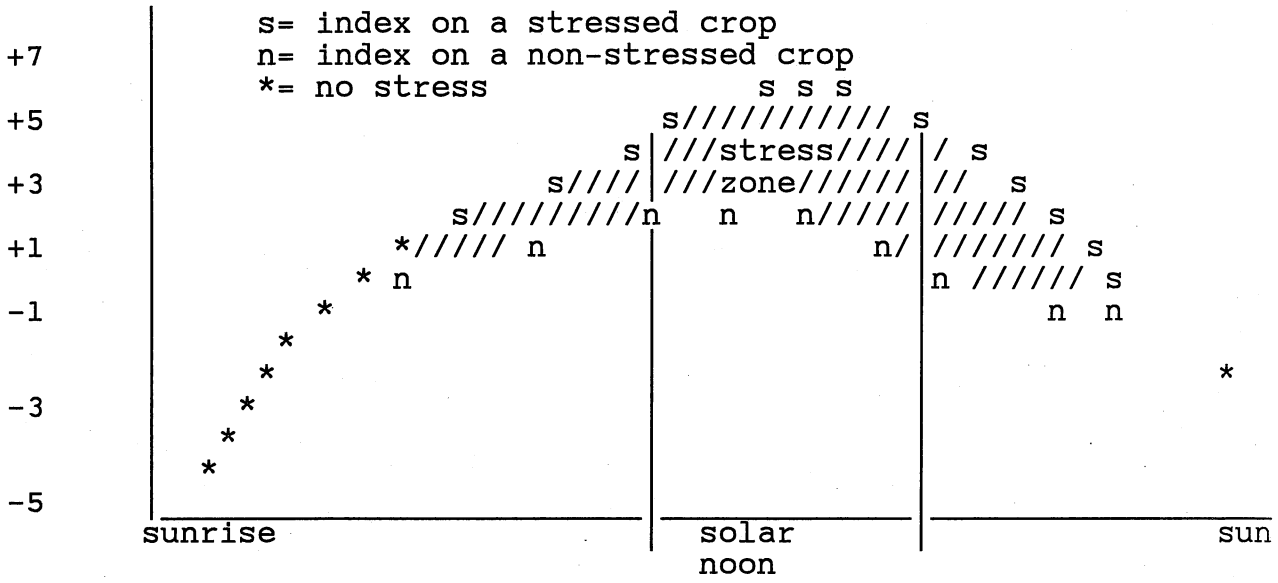
Alfalfa, almonds, apples,asparagus, barley, cantaloupe, carrots, corn, cotton, cucumber, grapes, grapes, jojoba, pecans, potatoes, sorghum, soybeans, sugar beets, tomatoes, watermelon, and wheat.

Equations cannot be developed for some crops. For example, the leaves of lemons and oranges are thick and waxy. They evaporate water slowly at best. There is no consistent difference in temperature between stressed and non-stressed leaves for these crops. This makes any equation developed unreliable for these type of crops.

It is not essential to have a set of equations developed for a particular crop. General purpose equations called "HIGH" and "LOW" have been developed for use on crops other than those listed above. "HIGH" is often used on plants with tall canopy structures, such as tress, and "LOW" is often used on plants which grow low to the ground (such as onions). These equations will probably not produce a typical 0 to 10 scale. Instead, the customer will need to use them for a while to learn what to expect. But at least he will be able to get started.

HOURLY INDEX TRENDS

The index is not constant from hour to hour. It varies with the sun.



You should already know about sunrise and sunset, but what in the world is "solar noon?" In the Old West, another name for solar noon was "High Noon." Solar noon occurs when the sun is exactly half-way between sunrise and sunset. The sun is brightest and hottest at this time. Solar noon can occur anywhere between 12:00 p.m. and 2:00 p.m., depending on where you live and whether or not you are on daylight savings time or standard time. The easiest way to determine solar noon is to use the old Boy Scout trick of placing a stick in the ground. When the shadow of the stick points directly south, it is solar noon.

You can see from this graph that you have a relatively limited "window of opportunity" to make your stress readings. As stress becomes more and more severe, this window becomes wider. Crop managers are usually interested in avoiding severe stress. When stress is first indicated during this mid-day period, the crop is basically non-stressed the rest of the day. By operating near this mid-day peak, you are using the Scheduler at its best.

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Points to Remember

Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour. Be consistent on the time of day you make measurements.

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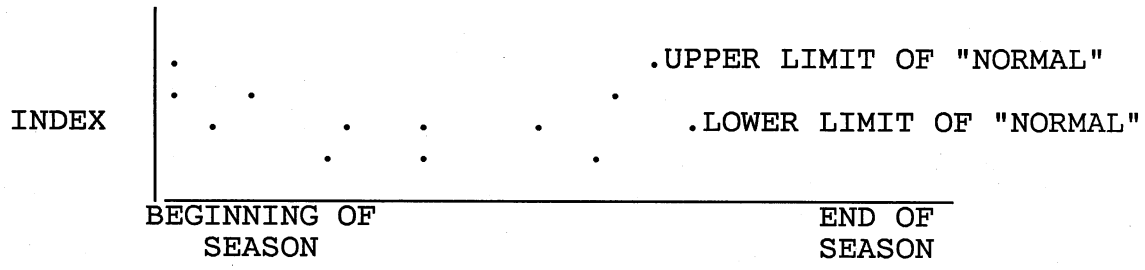
SEASONAL TRENDS

The pattern of the index between sampling dates is VERY important.

The first thing you need to know is "what's normal for this crop?"

The second thing you need to know is "how does this field compare with "normal?"

YOU MUST UNDERSTAND THE BIG PICTURE IN ORDER TO UNDERSTAND INDEX READINGS. The index for every crop has a normal pattern. For example, a row crop, such as cotton, would have a seasonal pattern like the one shown below The dotted lines represent the upper and lower limits to normal readings. If an index value is above the upper line, the crop is under stress. If an index value is below the upper line, it means the crop is not under stress.



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The normal management objective on most crops is to either have the index decrease with time, or be stable with time. An index is "stable" with time, if it stays within a zone about 3 index units wide. For example, readings would be considered stable if they remained between -2 and 0 or if they remained between 1 and 3. Many users can maintain a zone of stability with smaller limits than these, especially users who have drip irrigation systems. When you are analyzing index patterns, the key is the trend (increasing, decreasing, or staying flat).

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NEGATIVE INDEX VALUES

When we calculate an index, we compare the actual temperature of the crop (measured with an infrared thermometer) with our baseline. If the actual temperature of the crop is less than our baseline predicts, it means that the crop is cooler than expected. The index will be negative. It is normal to find that measured values of the index are 1 to 2 units below our baseline, i.e., the stress index will be -1 to -2. If the index is more negative than -2, possible explanations are:

- The crop is exceptionally cool, could be wet from rainfall or irrigation or simply using an excessive amount of water. Negative index values are correlated with low pressure chamber readings.

- The sunlight intensity was too low. This can happen quite easily. Mistakes which can cause negative index values include:

  . Clouds in front of the sun. On a cloudy day, the plants are under much less stress than on a sunny day. The manager is concerned about the maximum stress plants exhibit, not the minimum. All measurements must be made with bright sunlight on the plants.

  . Too early or too late in the day. This may not be so obvious, especially if it has been a hot day and the air temperature is still high. The "window of opportunity" is longer during the summer than in the winter. Learn when solar noon occurs in your area. Reference all recommended sampling times to solar noon.

  . You aimed at the shaded part of the canopy. We strongly recommend you keep the sun at your back as a standard practice. This insures you will be looking in the direction of the maximum number of sunlit leaves. This is not necessary on some crops (such as alfalfa) but is always good practice. Make it a rule.

  . You aimed too far from the point where you were standing and included the sky in your measurements. This problem is avoided by using proper aiming techniques.

- Air temperature is unusually cool, but the sunlight is bright. In this situation, the crop is also unusually cool, producing a negative index. There is nothing that can be done about this situation. There is also nothing to worry about from a water stress viewpoint. The index is right: the crop is not too hot.

- The sensor gun was too hot. The gun may have been left in a hot truck. If this happens, be sure to allow plenty of time for the instrument to cool off.

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Points to Remember

- Clear skies and time of day are critical considerations.
- Negative index values are normal.
- Negative index values indicate no stress.
- Mistakes can artificially create negative index values.
  - Crop is wet
  - Wrong time of day
  - Poor aiming technique
  - Unusually cool air
  - Sensor gun was too hot

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POSITIVE INDEX VALUES

Positive index values occur for two reasons:

1. Because the crop is hotter than the baseline predicts.

2. The sensor gun is cold. If the gun is stored in a cool room and then taken outside on a hot day, the index values will be too high for the first few minutes.

The index can be greater than 10. There are two reasons why. First, bare soil can influence the index. If you aim so that some soil is measured, the index could exceed 10. Second, we are purposely conservative in how we estimate the maximum stress line. This allows us to give greater sensitivity to the index. Severely stressed crops may exceed 10.

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Reasons the index can be above normal:

- Crop is under stress
- Sensor gun is too cold

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FACTORS WHICH INFLUENCE THE INDEX

Anyone who is experienced with plants knows that many cultural practices affect plants. Anything that affects a plant has the potential to affect the index. Factors which are known to influence index values include:

- Variety. With some crops, such as corn, varietal differences appear to be small. Some crops, such as grapes, appear to have significant varietal differences caused primarily by leaf size differences. The spread in index readings may be up to 2 index units. This does not mean that you need a separate baseline for each variety. It does mean that a user will probably have to use the Scheduler for a season on a particular variety before he will know what to expect for normal index readings.

- Wind. Studies indicate that wind speed fluctuations can cause a variation in plant temperature of 2 to 4 degrees F. This means that CWSI can be expected to fluctuate up to about 2 stress units as the wind speed varies. The key to obtaining accurate index numbers is sampling technique. Remember, plant temperature (and CWSI) are both fluctuating around a fairly stable average. Effective sampling technique will produce a good estimate of that average.

- Time of day. Plant temperatures are controlled by the sun. The sun changes in brightness (and its heating power) throughout the day. The sun is usually brightest and hottest at "high noon", or when the sun is directly south. There is only a small difference in the brightness or heating power of the sun plus or minus 1 hour of solar noon. Because the maximum air temperature for the day usually occurs after solar noon, the best time to sample is about 1 hour after solar noon. More about solar noon in the next section.

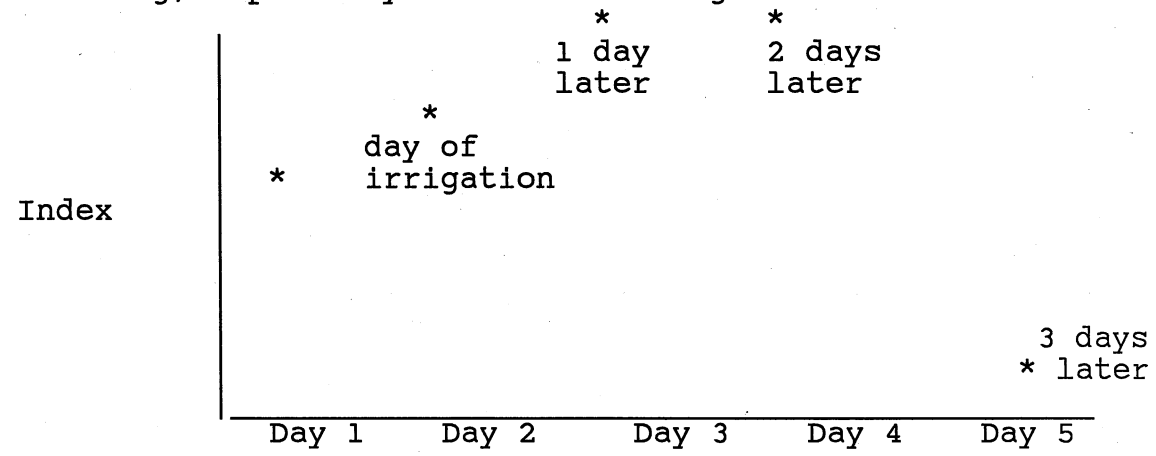
- Clouds. Clouds protect plants from the sun. You feel cooler when you step from the sun into the shade. Plants are cooler when the sun is behind a cloud. The index value which is of most value to a grower is the index value obtained when the sun is shining brightly. The index value will always be lower when the sun is behind a cloud than it is when the sun is shining.

- Soil. Hot, dry soil will influence index readings. Remember, bare soil also has a temperature and an index value. Below are some index values for bare soil at various soil temperatures (assume air temperature is 90o F and relative humidity is 30%. The index values given are for cotton):

Soil Temperature	Index Reading
80	-1.0
90	6.1
100	13.3
110	20.5
120	27.6
130	34.8
140	42.0
150	49.2

You can see that soil temperatures may have no impact at all on index readings or the impact can be extremely strong. The hotter the soil temperature, the greater the impact. You must be careful to avoid soil in your readings.

- Too much water. Over-irrigation can affect the index (it affects plants also). The reason is simple: plants need water and air in the soil in order to function properly. It would not be unusual to see the following, especially with flood irrigations:



WHAT'S GOING ON? Isn't an irrigation suppose to make stress go away? In theory, yes, but in reality, some irrigations (for a few days) create stress. The reason is simple: heavy irrigations force the oxygen out of the soil. Without oxygen, plant roots are unable to use soil water. So, if you run out to the field the day after an irrigation, don't be suprised if you see the stress levels increase instead of decrease.

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The Scheduler is not a voltmeter which provides exactly the same answer every time you turn it on. The basic reason for this is that an agricultural crop is dynamic. It responds to a constantly changing environment. The guidelines we provide will be useful to initially judge the meanilng of Scheduler data, but some user adjustments are inevitable.
****

SCHEDULER Hardware Features

- Aspirated air temperature and humidity sensors.

- Infrared thermometer
  - Distance: one inch to infinity
  - Range: + 108oF from ambient
  - Field of view: 8o
  - Spectral response: 8-14 um
  - Accuracy: + 1.0oF
  - Repeatability: + 0.4oC
  - Emissivity: 0.99
  - Operating distance: 1 inch to infinity

- Ambient temperature
  - Range: 32oF to 140oF
  - Accuracy: + 1.0oF
  - Resolution: 0.2oF

- Humidity
  - Range: 0 to 100%
  - Accuracy: + 5%

- Solar Radiation:
  - Range: 0 to 100 mW/cm2
  - Accuracy: + 10%

- Response Time:
  - Screen update < 2.0 seconds
  - Sample frequency < 0.5 seconds

- Microprocessor: 64-K -- 8 bit.

- Display: 2-1/2 X 1-1/2 LCD on processor
  1-1/2 X 1 inch on sensor gun

- Serial Interface:
  - RS-232 25 pin male connection
  - Baud Rates: 50-2400 (selectable)
  - Character Sizes: 5-8 (selectable)
  - Other download parameters also selectable

- Softside carry case.

- Warranty: 1 year

- Power -- 6 C cell batteries, with an expected life of 20 operating hours.

- Recharging port provided for use with rechargeable batteries.

HARDWARE REQUIREMENTS
FOR MEASURING CROP WATER STRESS

Instruments designed to measure water stress should:

1. Measure canopy temperature accurately. Plant temperature is the key to understanding plant behavior. Everything that a plant does is controlled by the temperature of the plant.

2. Be portable. this would allow measurements to be made anywhere that is desired. The instrument must not weigh too much or be too clumsy to use.

3. Be rugged and sturdy for use in the field. Any piece of equipment used in the field is exposed to jarring, bouncing, hot and cold temperatures, and dust (among other things). Many "laboratory quality" instruments would be destroyed by the way farmers would handle them. If it isn't rugged, don't use it in the field.

4. Allow for multiple readings in the field.
The reason is simple : fields are variable.
One section may have a heavy soil, another section may have salt problems. One sample of one plant is a poor representation of the overall average. It must be possible to sample many plants in order to have confidence that the reading represents the true average.

5. Be simple to use. No matter how good it is, if it isn't simple to use, most growers will not use it.

6. Correlate well with physiological measurements. Instrument readings must make sense. The instrument must be designed to provide information which relates directly to the condition of the plant. This means the scientific basis for the instrument must be strong. The Scheduler design fulfills these requirements.

BENEFITS OF THE SCHEDULER

The Scheduler helps in the following areas :

- Large acreages. Growers have a need to obtain information rapidly about many different sections of their operation. The Scheduler was designed specifically to obtain information rapidly. Current grower techniques are often based on small samples of a few plants or localized soil samples.

- Manpower. Growers may have an insufficient number of trained people to help. They need inexpensive assistance in obtaining quality information about the current condition of their crop. When you look at the number of acres that one person can monitor with a Scheduler, the cost of the unit is very small on a per acre basis.

- Uniformity. Some sections of the farm may be in super condition, and other sections may have some real problems. Ultimately, this costs the grower money. Many problems are induced by the grower because growers do not have the information they need to discriminate differences in crop condition between areas until visual symptoms occur, at which point yields are often already damaged. The Scheduler allows a grower to manage sections so that stress levels remain as uniform as possible.

- Confidence in current techniques. Many of the current techniques growers are using are not very satisfactory. There is often a desire for something better. We believe the Scheduler is better than other devices growers use.

- Documentation. Growers like to see "the season at a glance." To do this with current techniques requires a great deal of effort in learning to understand computers, in developing software, and in entering data into a computer.

SUPPORT SOFTWARE

The Scheduler support software was designed to run on any IBM compatible personal computer.

You may operate the program directly from the floppy disk or you may run the program from the hard-drive. Your hard disk must have at least 180,000 bytes of available storage space; one serial port;one floppy drive; 256 Kb RAM; a monochrome or color monitor (the program does not use colors); DOS 3.0 or higher (DOS 2.0 should work, but there is a potential that it won't. Try it and see).

The Scheduler analysis software is provided on 3.5 " or 5.25" floppy disks.

FEATURES

There is one MAIN menu and one UTILITIES menu. From either menu, you simply press the indicated letters or numbers to select the option you want.

MAIN MENU

	Options	Purpose
Main Menu	---IMPORT---	--imports data from the Scheduler and stores it in a data base
	---PRINT----	--prints the Scheduler data most recently imported
	---TODAY----	--makes graphs of the most recently imported Scheduler data only
	---PATTERNS-	--shows you where the hot/cool and stressed/non-stressed are
	---HISTG----	--makes graphs using the historical data base
	---HISTP----	--prints reports using the historical data base
	---UTIL-----	--utilities menu options

UTILITIES MENU

Utilities Menu	----F----	edit the names of the Scheduler field numbers.
	----S----	change the SET-UP options
	----L----	load demonstration data.
	----T----	serial port test.
	----D----	display the curent directory
	ALT-E---	selectively exports data to an ASCII file
	ALT-I---	imports Scheduler data from an existing file
	ALT-R---	resets the historical data base
	----E----	identifies the type and source of any hardware/software errors

COMPARING THE SCHEDULER TO OTHER TECHNOLOGY

Yes, there is more than one way to measure plant stress. One request which we constantly hear goes something like this "Well, what is the relationship between the stress index and whatever it is that the customer is currently using?" The idea is that it would be very nice if we could make an index reading and tell the customer "This reading is equal to XXX soil moisture, or XXX tension, or XXX pressure potential, etc."

Yes, that would be very nice. But it's not going to happen. There is , in general, a strong relationship between Scheduler readings and other measurements. But too many unknowns exist to develop generalized 1:1 relationships. If you want to know plant water potential, then measure it with a pressure chamber. If you want to know soil moisture, then measure it with a neutron probe. If you want to know the stress level, then measure it with a Scheduler.

LITERATURE SUMMARY

Relationship of Leaf and Air Temperature

Lomas et al. (1971) stated that the relationship of leaf temperature (TL) to air temperature (TA) was dependent on weather and soil moisture conditions. They observed that moisture stressed potato leaves were 7-9 C warmer than air temperature.

Lange (1965) identified five important factors affecting the difference between leaf and air temperature (in order of relative importance): (1) net radiation (sunlight intensity and stability) (2) transpiration rate (stress status) (3) convective heat exchange with the surrounding air (windspeed). (4) the exchange of chemical energy within the plant. (5) heat exchange due to water exchange within the plant.

Linacre (1964a) examined representative leaf temperature versus air temperature data for non-stressed plants. He theorized that in sunny moist climates the cross-over point -- the point at which leaf and air temperatures are equal -- is about 33 C. Field research by others suggest that leaf and air temperatures may be equal over a fairly broad range of ambient conditions. Mid-day cross-over points between 23 and 34 C have been observed in cotton, corn, alfalfa, sorghum and soybean (Palmer, 1965; Blad and Rosenberg, 1976a; Steinmetz, 1977).

Early morning leaf temperatures of corn, alfalfa, sorghum, soybeans and grass have been observed to be nearly equal to or cooler than air temperature in Nebraska (Blad and Rosenberg, 1976a; Steinmetz, 1977) in Australia (Palmer, 1965) and in Arizona (Ehrler and van Bavel, 1967; Ehrler, 1973). Leaf temperatures increase more rapidly than air temperature during the morning hours, resulting in less negative values of dT (dT = TL - TA during that period. By mid-morning, the energy balance shifts and dT starts becoming more negative. By mid to ate afternoon dT is generally at its most negative value (Palmer, 1965; Stone et al., 1975; Blad and Rosenberg, 1976a; Steinmetz, 1977; Sumayao et al., 1977). Gates (1968, 1969, 1973) published data showing that dT ranges from -8.9 C to +21.5 C, depending on plant species and ambient conditions.

dT has been related to decreasing soil moisture content in potatoes (Lomas et a., 1971); cotton (Bartholic et al., 1972) and sorghum (Sumayao et al., 1977; to lower leaf-water potential in cotton and wheat (Bartholic et al., 1972; Ehrler et al., 1978a, b); to reduced transpiration in potatoes (Lomas et al., 1971), sorghum (Sumayao et al., 1977) and wheat (Jackson et al., 1977); and to increased vapor pressure deficit (Ehrler, 1973).

Factors Affecting Leaf Temperatures

Leaf temperature is a function of air temperature, radiation intensity, wind velocity, leaf dimension, leaf thickness and the angle of leaf orientation with respect to impinging radiation (crop geometry) (Ansari and Loomis, 1959; Thofelt, 1975). Other important factors are transpiration, vapor pressure deficit (Ehrler and van Bavel, 1967 ;Wiegand and Namken, 1966) and leaf position on the plant (Waggoner and Shaw, 1952).

Wiegand and Namken (1966) showed a linear relationship between solar radiation and leaf temperature. Wiegand and Swanson (1973) reported that cotton leaves require 30 seconds to 1 minute to reach a new equilibrium temperature when solar radiation intensity changes. Stone et al. (1975) observed changes in sorghum leaf temperatures of up to 3 C with fluctuating solar radiation.

Plant Responses to Moisture Stress

Hsaio (1973) summarized the observed plant responses to water stress, which include reductions in the transpiration rate, CO2 assimilation and respiration rate, cell size, plant-water potential, growth rate, total protein synthesis and stomatal aperture diameter. Increases occur in leaf temperature, mesopyll resistance and total free amino acids. He stated that these responses to moisture stress seem to represent general patterns of modulation in plants under adversity. He concluded that the effects of water stress must be evaluated in terms of the severity and duration of the stress and of the plant species involved.

Stomatal Response

Ehrler and van Bavel (1967) stated that the regulation of transpiration by the leaf stomates is of specific importance to water use and its efficiency in crop production. They indicated that as leaf water deficits develop, stomates close, leading to decreases in transpiration and increases in leaf temperature.

Clark (1973) stated that stomatal resistance in peas increased as moisture stress developed, resulting in increased leaf temperatures. He concluded that the status of water in plants represents an integration of the atmospheric demand, soil-water potential, rooting density and distribution and other plant characteristics. He stated that, for a true measure of plant moisture stress, measurements should be made on the plant instead of the soil or atmosphere.

Vegetative Growth and Yields

The effect of moisture stress on vegetative growth and yields depends on the degree of stress and on the state of growth at which stress occurs (Somerhalder, 1962; Sionit and Kramer, 1977). Denmead and Shaw (1960) observed that stress in corn during silking was more harmful to grain yields than stress during any other growth stage. They suggested a possible tendency for recurring periods of stress to have increasingly smaller effects on yield.

Sionit and Kramer (1977) showed that soybeans stressed at different growth stages responded differently in terms of yield and of oil and water content of their seeds. Moisture stress was most detrimental when it occurred during pod formation and filling. Reicosky et al. (1975) theorized that a physiological change occurs in corn during pollination which makes the interpretation of leaf water potential measurements after that stage difficult.

The Measurement of Water Stress

Kramer (1963) listed five desirable characteristics for any method used to measure moisture stress: (1) the measurement should correlate well with rates of physiological processes; (2) the method should produce similar results when used on a wide range of plant material; (3) the technique should be applicable to soil; (4) the method should be simple and inexpensive and (5) the method should require a minimum of plant tissue for measurement. Scheduler index readings are directly related to transpiration rates (criteria 1); are useful on a wide range of plant material (criteria 2); relate to soil moisture deficits (criteria 3); are simple and inexpensive to make (criteria 4) and require no plant tissue for measurement (criteria 5).

Measurements of Leaf Temperature

Moisture stressed leaves have been consistently reported as being warmer than non-stressed leaves. Reported differences between stressed and non-stressed leaves for various crops range from 5 to 24 F .

Tanner (1963) suggested that the temperature difference between stressed and non-stressed potato leaves was a qualitative indication of transpiration differences. He concluded that, with a better understanding of transfer processes at the plant surface, leaf temperature measurements could provide quantitative data on plant water status. Since Tanner's article was published that understanding has been acquired.

Ehrler (1973) stated that leaf temperature measurements are an indirect indication of stomatal behavior. Ehrler et al. (1978a) demonstrated that canopy temperature in wheat increased as plant water potential decreased. Differences in canopy temperature between stressed and non-stressed wheat plants were shown to be a reliable indicator of plant moisture stresses.

Instruments which measure leaf temperature should fulfill four basic requirements: (1) the radiation balance of the leaf should not be disturbed; (2) the real temperature of the leaf should be measured with sufficient accuracy: (3) it must be possible to take repeated readings with the instrument and (4) the instrument should be transportable and sturdy enough for use in the field (Lange, 1965). The Scheduler fulfills these requirements.

Managing Irrigation using Plant Temperatures

Ideally, the plant should signal when to irrigate and the soil should indicate how much water to apply (Teare et al. 1974). Aston and van Bavel (1972) and Nixon et al., (1973) suggest that large canopy temperature variability within a field should signal the onset of soil moisture deficits due to the non-homogeneous moisture retention properties of large fields. Ehrler (1973, 1978b) showed that the leaf-air temperature differential could be used to signal the need for irrigation. Ritchie (1977) suggested using the temperature difference between stressed and non-stressed plants to detect the occurrence of soil moisture deficits.

Brown and Rosenberg (1973) defined a model to estimate evapotranspiration (ET) using crop temperature. Hourly estimates of ET were within five percent of energy balance estimates. Daily estimates of ET over alfalfa were within 10 percent of estimates made by energy balance (Blad and Rosenberg, 1976b).

Jackson et al. (1977) developed an expression for relating ET to net radiation and crop temperature:

$$ET = Rn - B(Tc-Ta)$$

Tc is crop temperature, Ta is air temperature Rn is net radiation and B is a calibration coefficient.

Canopy temperature measures have been used to estimate ET rates in sugarbeets and cotton (Brown and Rosenberg, 1973); sorghum,soybeans and millet (Stone, 1974; Heilman et al., 1976); alfalfa, beans and grass (Idso et al., 1977) and wheat (Jackson et al., 1977).

Jackson (1982) summarized the history of infrared thermometry and described a USDA method of quantifying water stress. The index he describes is known as the Crop Water Stress Index or CWSI. CWSI is defined as:

$$CWSI = (Tc - T\ min)/(Tmax-Tmin)$$

where: Tc = measured canopy temperature
T min = minimum canopy temperature for a given set of meterological conditions
T max = maximum canopy temperature for a given set of conditions. Experimental data is presented which shows that CWSI is strongly related to soil moisture content in wheat. This index is the basi for the index used in the Scheduler.

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1989 SCHEDULER TRAINING

CHAPTER 1 - CWSI THEORY

1.1 A Simple Principle

CWSI (crop water stress index) is based on a simple principle. Any surface which is evaporating water at a high rate will be cooler than a similar surface that is not evaporating water as fast. You have probably experienced this principle many times. Recall a summer day at the beach. Before diving into the water, the summer sun made your skin feel warm. After you emerged from the water, you felt much cooler. Why? Simple. Your skin was evaporating water much faster when it was wet than when it was dry.

In a similar fashion, a leaf that is supplied with adequate water (non-stressed) will evaporate water faster than a leaf that has inadequate water (stressed). The result will be a difference in temperature between the non-stressed and the stressed leaves.

Back to the beach. If you felt too hot at the beach, you had two options to cool down, first, you could jump into the water, second, you could just walk into the shade. Isn't it amazing how much cooler you feel standing in the shade than when standing in the sun?

Plants react much the same way. Whenever a cloud moves in front of the sun, their temperature will also decrease. This means that whenever we want to compare stressed and non-stressed plant temperatures, we must be careful to make that comparison under the same sunlight conditions. It makes no sense to compare the temperature of a leaf in the shade with a sunlit leaf. The sunlit leaf will always be hotter. (Have you ever felt hotter in the shade than in the sun?)

1.2 Plant Temperature Research

Many scientists have studied plant temperatures during the last 150 years. A few were able to capture and understand the relationship between the plant's temperature and its overall health. Accurate temperature measuring devices were needed to advance the practical use of plant temperature. Only during the last 10 years were the first reliable hand-held infrared thermometers manufactured and commercially available to advance the use of this technology. Following is a summary of the major facts which have been reported.

1875 -- Thin leaves are cooler than thick leaves.

1905 -- Sudden increases in wind speed causes a decrease in plant temperature.

1915 -- The leaves of evergreens are much hotter than the air during winter (that's how they survive and photosynthesize).

1923 -- USDA researchers in Arizona showed that healthy leaves of various crop plants are cooler than the air during mid-day.

1929 -- The USDA confirmed that healthy cotton leaves can be 8 F or more cooler than the air.

1938 -- Garden plants can be as much as 14^{o}F below air temperature.

1052 -- The temperature of tomato and potato leaves are nearly the same.

1962 -- A scientist developed equations which showed that if a leaf remains motionless while the wind blows, its temperature is controlled by the windspeed, but if the leaf flaps, water evaporation controls leaf temperature.

1966 -- Infrared thermometers were first used to measure leaf and canopy temperature. The importance of solar radiation and time of day was emphasized.

1971 -- Leaf water content is correlated with leaf temperatures and relative humidity.

1973 -- Leaf water potential, stomatal resistance and leaf-air temperature differences are all correlated.

1973 -- A USDA scientist suggested using leaf-air temperature differences to schedule irrigations.

1981 -- USDA scientists developed the crop water stress index (CWSI).

In 1984, Standard Oil Engineered Materials Company (The Carborundum Company) conducted the first large scale field test of the CWSI concept. Prior to that time all the research had been conducted on small plots. Standard Oil Engineered Materials has been the driving force behind the technology transfer of CWSI from the theoretical domain of research scientists to the practical world of growers.

1984 -- First field test of CWSI concept.

1985 -- Multi-state field tests of CWSI.

1986-1988 -- Field tests continue. Simultaneously, the marketing/commercialization of the Scheduler was begun.

Between 1978 and 1988, the literature has exploded with information which demonstrates that canopy temperatures can be used to schedule irrigation and monitor crop condition on a wide variety of crops.

Standard Oil Engineered Materials has collected CWSI information from over 125 separate locations (experiments and grower fields). No other infrared thermometer company has been involved in CWSI research of this magnitude. We have conducted more CWSI research than the combined efforts of several university research departments.

The Scheduler is a new tool which helps answer questions that could never be asked prior to its invention. Plants are amazingly complex in their behavior and some questions will take years to answer. The important point is that **sufficient knowledge exists to allow growers to benefit from monitoring the condition of their crops.**

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Points to Remember

- **Non-stressed leaves are usually cooler than the air.**
- **Plant temperature is related to plant health. A plant that is "stressed" will (when the sun is shining brightly) will be hotter than a healthy "over-stressed" plant.**

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Do not be afraid to ask questions. Once you master the basics, you will start to feel comfortable with the Scheduler.

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1.3 Important Scientific Conclusions

The following statements summarize the conclusions of agricultural scientists concerning plant temperatures during the period 1929 - 1988. There is little room for doubt that leaf temperatures are considered very important.

"The facts suggest that the differences in yields are associated with the observed differences in their leaf temperatures." (Eaton and Belden, 1929).

"...transpiration invariably tends to lower the temperature of the transpiring leaf...." (Curtis, 1936).

"Leaf temperature relative to air temperature can be predicted..." (Waggoner and Shaw, 1952).

"Thus a sensitive measurement of the temperature difference between plant samples may provide an indication of transpiration differences." (Tanner, 1963).

"The temperature differences between well-watered and stressed crops should indicate a relative need for irrigation. Within large irrigation projects it should be possible to identify fields needing irrigation from crop canopy temperature information. Within individual fields plants in areas not irrigated adequately should stress sooner and have a higher canopy temperature than the nonstressed plants in well-watered surrounding areas." (Bartholic et al., 1972).

"On a given day, relative leaf water content and leaf temperature were highly correlated." (Carlson et al., 1972).

"Field studies at this laboratory have shown Tc-Ta to be a sensitive guide to changes in stomatal aperture, as measured by leaf resistance." (Ehrler, 1973).

"...measurement of Tc-Ta still appears adequate for assessing soil water status effects on crop vigor and signalling needed irrigation ..." (Idso and Ehrler, 1976).

"The results indicate that the temperature differences between the stressed and the unstressed plants arises primarily from differences in transpiration. It is further suggested that after proper calibration, plant temperature promises to be a reliable index for identifying crop water deficits and for optimizing irrigation scheduling." (Sandhu and Horton, 1978).

"The results of this experiment suggest that knowledge of leaf and air temperatures, which are relatively easy and inexpensive to determine, can be useful in assessing the water status of corn and sorghum." (Sumayao et al., 1980).

"The results demonstrate the ability of surface temperature measurement by means of infrared thermometry to rapidly assess large areas of cropped land for plant water potential depressions arising from shortages of soil moisture." (Idso et al., 1981)

"We conclude that canopy temperature variability can be used to signal the onset of plant water stress...." (Clawson and Blad, 1981).

"...canopy temperature data can be used to track crop water stress and the effect of stress on yield...soil

factors indicate when plants may be stressed, plant factors indicate when they are stressed. Plant factors, such as water potential, are point measurements that require numerous samples to characterize a field. Canopy temperature measurements can minimize this problem." (Jackson, 1982).

"...linear regression analysis indicate close correlation between water stress index...and water potential..." (Tormann, 1986)

"The Infrared Thermometry device as represented by the "Scheduler" ...is a very sensitive and yet practical means of determining the water stress status of a crop such as vines. The neutron probe while quite accurate in its evaluation of soil moisture content did not provide any measurement of stress...The IRT device is as sensitive to plant stress as the porometer while more simple to operate and maintain than the other devices discussed above...If a known, unstressed vine is used as a reference and the indexes for the vines in question for that date are compared with the reference vine then the IRT method can be used very well for stress management." (Krauter, 1988).

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The Scheduler is based on very sound physical and scientific principles. Those who learn to use it first will be the furthest ahead.

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Points to Remember

- **Plant temperatures can be used to indicate plant stress.**
- **Higher than normal plant temperatures results in yield and quality losses.**
- **The hotter a plant is (relative to air temperature), the lower its transpiration rate.**
- **In the field environment, plant temperature variability is a sign that stress has <u>just begun</u>.**

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1.4 CWSI Theory

1.4.1 Definition of the Index

Think of the stress index as a percentage. You use percentages all the time. For example, sales commissions are often expressed as a percentage. A salesman wants this percentage to be as high as possible. But, what what kind of stress index reading should you want? Let's compare the index to a sales commission.

$$\text{percent profit} = \frac{[\text{sales commission}]}{[\text{retail price}]} \times 100$$

All your percentages are scaled between 0 and 100 % because you multiply by 100.

similarly,

$$\text{stress index} = \frac{[\text{actual stress}]}{[\text{possible stress}]} \times 10$$

All the stress index percentages are scaled between 0 and 10 because we multiply by 10.

If we could perfectly estimate the actual and possible stress (we can't) then the following chart would be true:

Index		
0	=	no stress detected
1	=	10 % of possible stress
2	=	20 % of possible stress
3	=	30 % of possible stress
4	=	40 % of possible stress
5	=	50 % of possible stress
6	=	60 % of possible stress
7	=	70 % of possible stress
8	=	80 % of possible stress
9	=	90 % of possible stress
10	=	100 % of possible stress

1.4.2 Calculating the Index

At this point, you're probably thinking "O.K., I can understand that much. But how do you measure 'actual stress' and 'possible stress.'" It's not really very complicated. In fact, it's really very easy. You can calculate an index without using a computer, equations or

anything fancy. All you need is some information. What information? All you need to know is:

- air temperature
- relative humidity
- plant temperature

The next step can be done by almost anyone: subtract air temperature from plant temperature. For example, if air temperature is 100° F and plant temperature is 95° F, then 95 - 100 = - 5. The plant canopy is 5 degrees cooler than the air.

Let's do that again, but this time use a simple equation:

Diff = Tc - Ta — Tc is just the plant temperature (or temperature/air) and Ta is just the air temperature. Let's put the numbers in.

Diff = 95- 100

Diff = -5 — Now we have a name for the number. The name is Diff, which stands for "the difference in temperature between a plant and the air temperature", (or the delta temperature

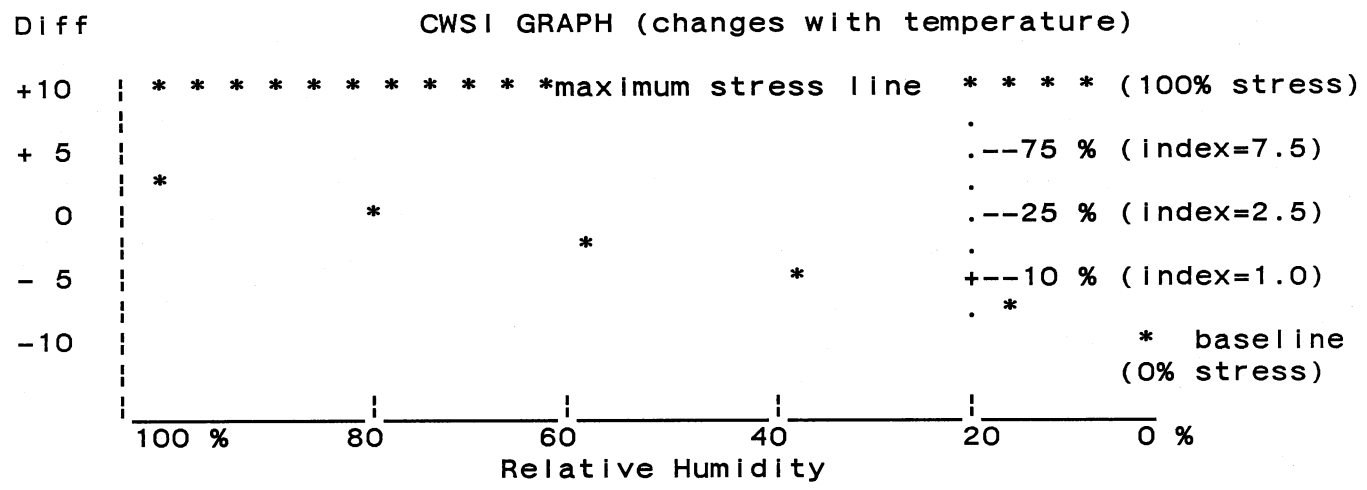
That's it. The information isn't mysterious. It's very simple. The math isn't hard at all.

Points to Remember

- The information you need to know to calculate an index is simple. Every one is familiar with air temperature and relative humidity. Plant temperature is the only new piece of information.

- The math is very simple

Now that you know the plants are 5 degrees cooler than the air, and suppose the relative humidity is 20%, just look at a graph like the one below:



This graph is not very complicated. The vertical axis is where we find the value of Diff (remember that subtraction we had to make ?). The horizontal axis is where we look up the relative humidity.

Ready? Let estimate the index for Diff= -5 and Humidity = 20%

First we just look on the vertical axis for the -5 then draw a line from left to right all the way across the graph. Next, look on the horizontal axis and find the 20. Now, draw a line from the 20 to the top of the graph. The two lines you draw will make a + somewhere. The + is where our sample data fits between two other lines.

Now, study the graph. Note that our sample data point is about 10% of the distance between the baseline (0% stress) and the maximum stress line (100% stress). Since our data point has traveled only 10% of the maximum possible distance, we say the index is 1.0.

What would the index be if Diff = + 5 and relative humidity was still 20%? (correct answer is 7.5).

Please note, the horizontal axis in the real index calculation is not strictly determined by the relative humidity but rather a combination of humidity and temperature called the Vapor Pressure Deficit (VPD).

1.4.3 Definition of a Baseline

It wasn't hard to calculate an index was it? All we needed was 3 pieces of information and a simple graph. But

graphs like the one you used in the sample are not found just anywhere. How is a graph like this made?

The index graph has two lines on it. The baseline is the line which shows us what the normal Diff (remember what Diff is?) value is for a healthy crop. The maximum stress line shows us what the highest Diff value is for a very sick (but still alive) crop. The basic process of making this graph is simple.

First, we use the Scheduler on healthy and stressed areas of a particular crop for as much of the season as we can. If we can collect data for more than one season, or in more than one location, so much the better. Two mathematical equations are then developed which effectively summarizes all this information, so that we can use it in a computer. One equation is called a baseline. The other equation is called the maximum stress line. The baseline represents 0% stress (or an index of 0). The maximum stress line represents 100% stress (or an index of 10). If the index was perfect, the index would never be less than 0 or greater than 10. In practice, the index will often be less than 0 and can exceed 10.

Equations have been developed for a number of crops, including:

Alfalfa, almonds, apples,asparagus, barley, cantaloupe, carrots, corn, cotton, cucumber, grapes, green beans, grapes, jojoba, pecans, potatoes, sorghum, soybeans, sugar beets, tomatoes, watermelon, wheat.

Equations cannot be developed for some crops. For example, the leaves of lemons and oranges are thick and waxy. They evaporate water slowly at best. There is no consistent difference in temperature between stressed and non-stressed leaves for these crops. This makes any equation developed unreliable for these type of crops.

It is not essential to have a set of equations developed for a particular crop. General purpose equations called "HIGH" and "LOW" have been developed for use on crops other than those listed above. "HIGH" is used on plants with slow transpiration rates and "LOW" is used on plants which are high consumers of water. These equations will probably not produce a typical 0 to 10 scale. Instead, the customer will need to use them for a while to learn what to expect. But at least he will be able to get started.

1.4.4 Negative Index Values

When we calculate an index, we compare the actual temperature of the crop (measured with an infrared thermometer) with our baseline. If the actual temperature

of the crop is less than our baseline predicts, it means that the crop is cooler than expected. The index will be negative. It is normal to find that measured values of the index are 1 to 2 units below our baseline, i.e., the stress index will be -1 to -2. If the index is more negative than -2, possible explanations are:

- The crop is exceptionally cool, could be wet from rainfall or irrigation or simply using an excessive amount of water. Negative index values are correlated with low pressure chamber readings.

- The sunlight intensity was too low. This can happen quite easily. Mistakes which can cause negative index values include:

  . Clouds in front of the sun. On a cloudy day, the plants are under much less stress than on a sunny day. The manager is concerned about the maximum stress plants exhibit, not the minimum. All measurements must be made with bright sunlight on the plants.

  . Too early or too late in the day. This may not be so obvious, especially if it has been a hot day and the air temperature is still high. The "window of opportunity" is longer during the summer than in the winter. Learn when solar noon occurs in your area. Reference all recommended sampling times to solar noon.

  . There is an error in the baseline. Once we have used a baseline for a while, baseline errors should not be significant. It is not hard to become accustomed to using a baseline that has an error in it. For example, the current tomato baseline consistently reads negative on healthy plants. Irrigation is needed when the index reads about 0 on tomatoes. We could adjust the baseline, but since we have learned how to use the current one, there is no need. In fact, it would confuse current users.

  . You aimed at the shaded part of the canopy. We strongly recommend you keep the sun at your back as a standard practice. This insures you will be looking in the direction of the maximum number of sunlit leaves. This is not necessary on some crops (such as alfalfa) but is always good practice. Make it a rule.

- You aimed too far from the point where you were standing and included the sky in your measurements. This problem is avoided by using proper aiming techniques.

- Air temperature is unusually cool, but the sunlight is bright. In this situation, the crop is also unusually cool, producing a negative index. There is nothing that can be done about this situation. There is also nothing to worry about from a water stress viewpoint. The index is right: the crop is not too hot.

- The sensor gun was too hot. The gun may have been left in a hot truck. If this happens, be sure to allow plenty of time for the instrument to cool off.

==========

Points to Remember

- **Clear skies and time of day are critical considerations.**

- **Negative index values are normal.**

- **Negative index values indicate no stress.**

- **Mistakes can artificially create negative index values.**

==========

1.4.5 Positive Index Values

The agronomic interpretation of positive index values may be different for each crop. For example, cantaloupes is a crop on which you want only small positive index values (0-1). Cotton can tolerate moderately positive index values (2-3) without any damage. Seed alfalfa requires large positive values (7-9) to produce seed. For this reason, we have written a series of KNOW-HOW bulletins to explain what we currently know about interpreting index values for a particular crop. These bulletins are revised as new information becomes available.

Positive index values occur for two reasons:

1. Because the crop is hotter than the baseline predicts.

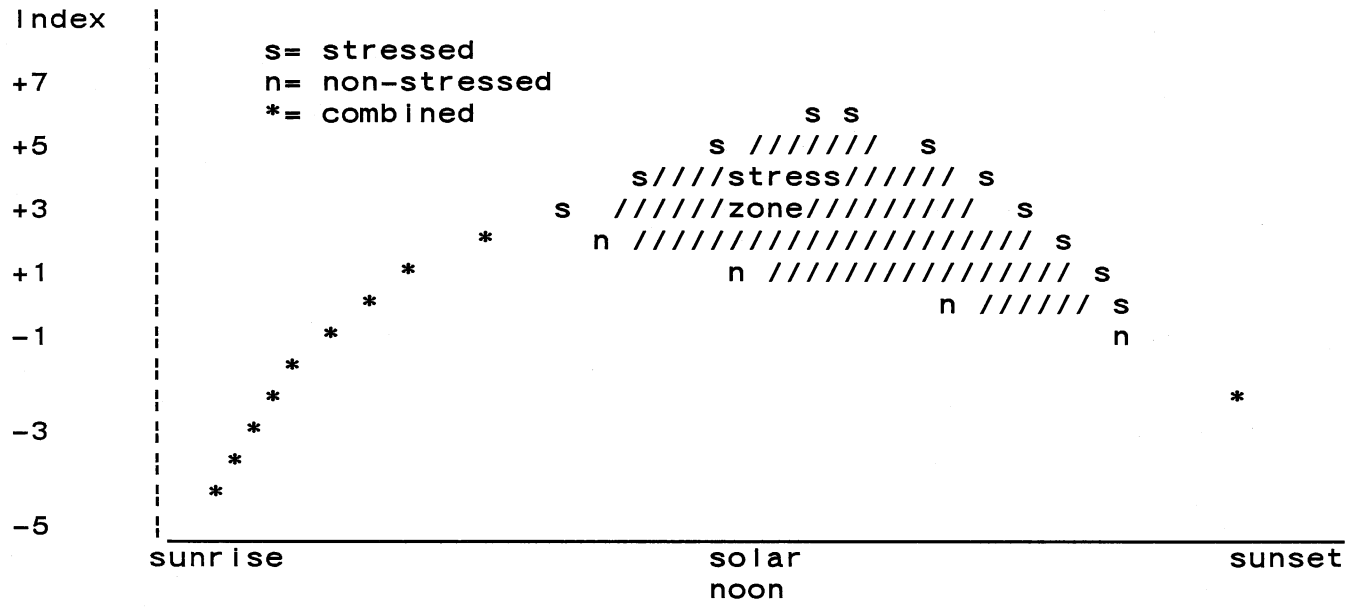
2. The sensor gun is cold. If the gun is stored in a cool room and then taken outside on a hot day, the index values will be too high for the first few minutes.

The index can be greater than 10. There are two reasons why. First, bare soil can influence the index. If you aim so that some soil is measured, the index could exceed 10. Second, we are purposely conservative in how we estimate the maximum stress line. This allows us to give greater sensitivity to the index. Severely stressed crops may exceed 10.

1.4.6 Index Trends

Hourly Trends

The index is not constant from hour to hour. It varies with the sun. The graph below shows the expected hourly pattern for a stressed and non-stressed crop.



You should already know about sunrise and sunset, but what in the world is "solar noon?" In the Old West, another name for solar noon was "High Noon." Solar noon occurs when the sun is exactly half-way between sunrise and sunset. The sun is brightest and hottest at this time. Solar noon can occur anywhere between 12:00 p.m. and 2:00 p.m., depending on where you live and whether or not you are on daylight savings time or standard time. The easiest way to determine solar noon is to use the old Boy Scout trick of placing a stick in the ground. When the shadow of the stick points directly south, it is solar noon.

You can see from this graph that you have a relatively limited "window of opportunity" to make your stress readings. As stress becomes more and more severe, this window becomes wider. Crop managers are usually interested

in avoiding severe stress. When stress is first indicated during this mid-day period, the crop is basically non-stressed the rest of the day. By operating near this mid-day peak, you are using the Scheduler at its best.

==========

Points to Remember

Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour.

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Daily Index Patterns

The pattern of the index between sampling dates is VERY important.

The first thing you need to know is "what's normal for this crop?"

The second thing you need to know is "how does this field compare with "normal?"

YOU MUST UNDERSTAND THE BIG PICTURE IN ORDER TO UNDERSTAND INDEX READINGS. The index for every crop has a normal pattern. For example, a row crop, such as cotton, would have a seasonal pattern like the one on the next page. The dotted lines represent the upper and lower limits to normal readings. If an index value is above the upper line, the crop is under stress. If an index value is between the lines, it means the crop is not under stress.

Reasons the index can be above normal:

- Crop is under stress
- Sensor gun is too cold

Reasons the index can be below normal:

- Crop is wet
- Wrong time of day
- Poor aiming technique
- Unusually cool air
- Sensor gun was too hot

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Points to Remember

You must know the BIG PICTURE for a crop to know what is normal.

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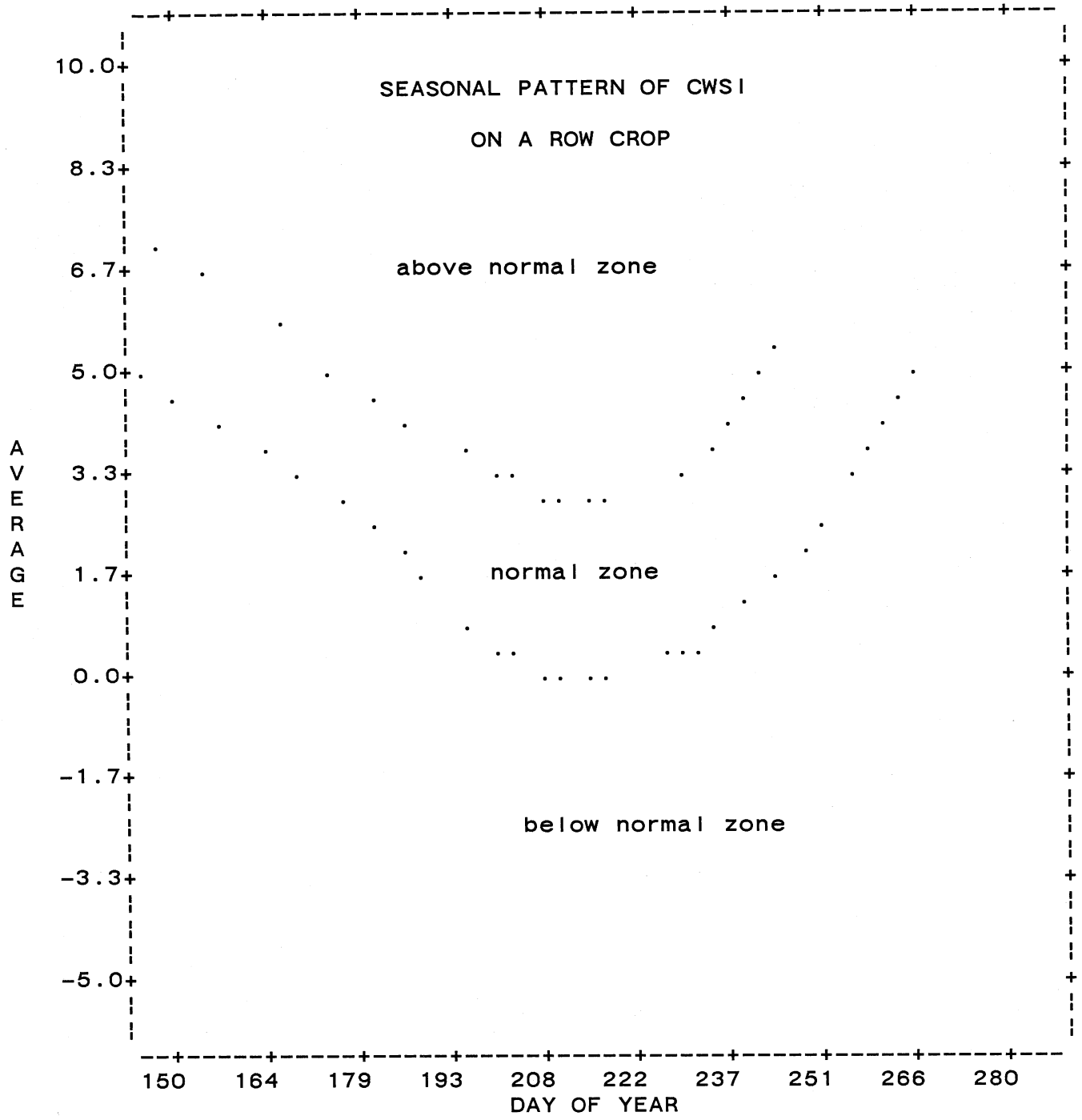
SEASONAL PATTERN OF CWSI
ON A ROW CROP
above normal zone
normal zone
below normal zone
10.0
8.3
6.7
5.0
3.3
1.7
0.0
-1.7
-3.3
-5.0
AVERAGE
150
164
179
193
208
222
237
251
266
280
DAY OF YEAR

Oops. There's a new term on the horizontal axis: "DAY OF YEAR". What's that? All we do is give every day in the year a number (there are 365 days in the year). So, January 1 is DAY 1, January 2 is DAY 2 etc. This table might help you understand:

Month	Days of Year
January	1-31
February	32-59
March	60-90
April	91-120
May	121-151
June	152-181
July	182-212
August	213-243
September	244-273
October	274-304
November	305-334
December	335-365

It's a little tougher to find a date on a graph using DAY OF YEAR values, but it's a whole lot easier to graph the information on a computer.

****

The normal management objective on most crops is to either have the index decrease with time, or be stable with time. An index is "stable" with time, if it stays within a zone about 3 index units wide. For example, readings would be considered stable if they remained between -2 and 0 or if they remained between 1 and 3. Many users can maintain a zone of stability with smaller limits than these, especially users who have drip irrigation systems. When you are analyzing index patterns, the key is the trend (increasing, decreasing, or staying flat).

****

1.4.7 Factors Which Affect Index Values

Anyone who is experienced with plants knows that many cultural practices affect plants. Anything that affects a plant has the potential to affect the index. Factors which are known to influence index values include:

- Variety. With some crops, such as corn, varietal differences appear to be small. Some crops, such as grapes, appear to have significant varietal differences caused primarily by leaf size differences. The spread in index readings may be up to 2 index units. This does not mean that you need a separate baseline for each variety. It does mean that a user will probably have to use the Scheduler for a season on a particular variety before he will know what to expect for normal index readings.

- Wind. Studies indicate that wind speed fluctuations can cause a variation in plant temperature of 2 to 4 degrees F. This means that CWSI can be expected to fluctuate up to about 2 stress units as the wind speed varies. The key to obtaining accurate index numbers is sampling technique. Remember, plant temperature (and CWSI) are both fluctuating around a fairly stable average. Effective sampling technique will produce a good estimate of that average.

- Time of day. Plant temperatures are controlled by the sun. The sun changes in brightness (and its heating power) throughout the day. The sun is usually brightest and hottest at "high noon", or when the sun is directly south. There is only a small difference in the brightness or heating power of the sun plus or minus 1 hour of solar noon. Because the maximum air temperature for the day usually occurs after solar noon, the best time to sample is about 1 hour after solar noon. More about solar noon in the next section.

- Clouds. Clouds protect plants from the sun. You feel cooler when you step from the sun into the shade. Plants are cooler when the sun is behind a cloud. The index value which is of most value to a grower is the index value obtained when the sun is shining brightly. The index value will always be lower when the sun is behind a cloud than it is when the sun is shining.

****

The Scheduler is not a voltmeter which provides exactly the same answer every time you turn it on. The basic reason for this is that an agricultural crop is dynamic. It responds to a constantly changing environment. The guidelines we provide will be useful to initially judge the meaning of Scheduler data, but some user adjustments are inevitable.

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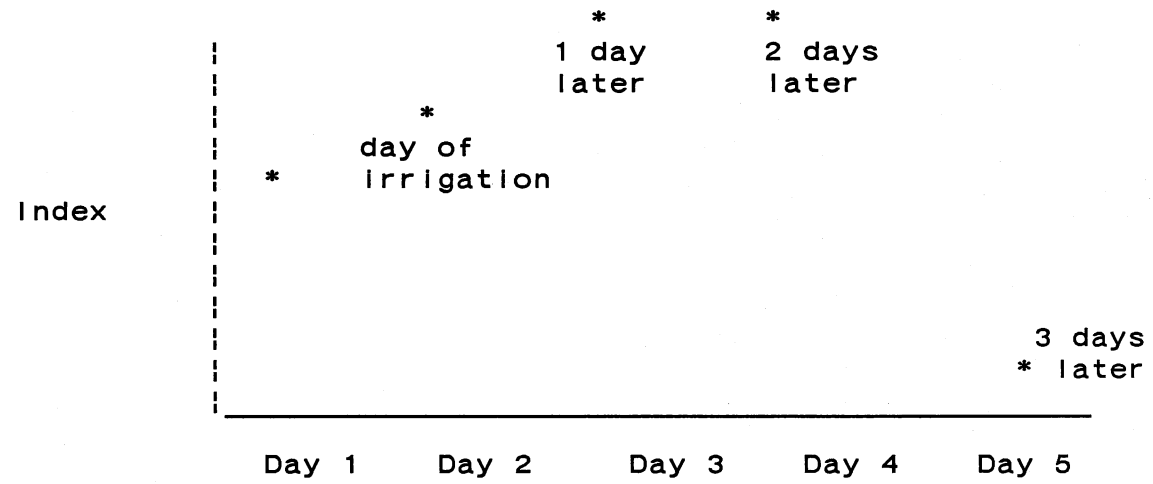
- Soil. Hot, dry soil will influence index readings. Remember, bare soil also has a temperature and an index value. Below are some index values for bare soil at various soil temperatures (assume air temperature is 90^{o} F and relative humidity is 30%. The index values given are for cotton):

Soil Temperature	Index Reading
80	-1.0
90	6.1
100	13.3
110	20.5
120	27.6
130	34.8
140	42.0
150	49.2

You can see that soil temperatures may have no impact at all on index readings or the impact can be extremely strong. The hotter the soil temperature, the greater the impact. You must be careful to avoid soil in your readings.

- Too much water. Over-irrigation can affect the index (it affects plants also). The reason is simple: plants need water and air in the soil in order to function properly. It would not be unusual to see the following:



WHAT'S GOING ON? Isn't an irrigation suppose to make stress go away? In theory, yes, but in reality, some irrigations (for a few days) create stress. The reason is simple: heavy irrigations force the oxygen out of the soil. Without oxygen, plant roots are unable to use soil water. So, if you run out to the field the day after an irrigation, don't be suprised if you see the stress levels increase instead of decrease.

1.4.8 Relating the Index to Other Measurements

Yes, there is more than one way to measure plant stress. One request which we constantly hear goes something like this "Well, what is the relationship between the stress index and whatever it is that the customer is currently using?" The idea is that it would be very nice if we could make an index reading and tell the customer "This reading is equal to XXX soil moisture, or XXX tension, or XXX pressure potential, etc."

Yes, that would be very nice. But it's not going to happen. Think about it this way. Let's suppose we want to develop a relationship between these two things: a) the type of house a person lives in and b) the income level a person has.

It takes no great stretch of the imagination to realize that these two things are strongly related. We could say, with a great deal of confidence, "In general, the more expensive the house a person lives in, the higher their income level". Right? This is just like saying "In general there is a relationship between the stress index and soil moisture, soil tension, and pressure potential.

In general. But now, an FBI agent comes to you and says "I want you to tell me the income level of Mr. X. Go take a look at his house, then return and tell me how much money he makes." Guess what! You couldn't do it. Despite the fact that you know "in general" the type of house a man lives in reflects his income, there is no way to predict this for a specific individual. There are simply too many other unknowns. For example, does his wife work or does he have a rich uncle, or is he deep in debt, etc.

This principle holds true for comparing stress index readings with other readings. There is, in general, a strong relationship between index readings and other measurements. But too many unknowns exist to develop general relationships. The index measures the stress level. Other techniques were designed to measure other things. If you want to know plant water potential, then measure it with a pressure chamber. If you want to know soil moisture, then measure it with a neutron probe. If you want to know the stress level, then measure it with a Scheduler.

1.5 INSTRUMENTS FOR MEASURING STRESS

1.5.1 Reasons for Needing Instruments

Growers have been producing crops for many years without using technical instruments to help them make decisions. So why should they start? After all, most growers know they can produce X tons per acre by making all their decisions "by the seat of the pants" or "experience." But, the truth is that plants have the potential to produce more than most growers achieve. A grower must have a desire to solve a problem before he will recognize the need to start using an instrument such as the Scheduler. Problems include:

- Large acreages. They have a need to obtain information rapidly about many different sections of their operation. The Scheduler was designed specifically to obtain information rapidly. Current grower techniques are often based on small samples of a few plants or localized soil samples.

- Manpower. They may have an insufficient number of trained people to help. They need inexpensive assistance in obtaining quality information about the current condition of their crop. When you look at the number of acres that one person can monitor with a Scheduler, the cost of the unit is very small on a per acre basis.

- Uniformity. Some sections of the farm may be in super condition, and other sections may have some real problems. Ultimately, this costs the grower money. Many problems are induced by the grower because growers do not have the information they need to discriminate differences in crop condition between areas until visual symptoms occur, at which point yields are often already damaged. The Scheduler allows a grower to manage sections so that stress levels remain as uniform as possible.

- Confidence in current techniques. Many of the current techniques growers are using are not very satisfactory. There is often a desire for something better. We believe the Scheduler is better than other devices growers use.

- Documentation. Growers like to see "the season at a glance." To do this with current techniques requires a great deal of effort in learning to understand computers, in developing software, and in entering data into a computer. The Scheduler provides a grower with two very useful forms of documentation.

1.5.2 The Plant is the Key

The ideal moisture stress reading is based on a direct plant measurement instead of a soil or atmospheric measurement (Clark, 1973). Think about this. Agriculture is concerned primarily with growing plants. Does it make sense to ignore information which comes directly from the plant? Of course not. It is important to understand that the plant is the best guide to its condition. Suppose you went to the doctor because you were feeling bad. Then, the doctor phones up the National Weather Bureau to find out the weather forecast. He then says, "Yup, I think you're probably going stay sick for about 3 or 4 more days." There's no doubt the weather is an important factor in making people sick, but wouldn't you feel just a little more confident in the doctor's diagnosis if he said "stick out your tongue and say AAAAH". Why do some growers feel they can ignore direct plant measurements and still achieve maximum productivity (and profit)? It doesn't make sense. The main reason farms exist is to produce plants and plant products. A manager has two choices:

- Measure the environment (soil, weather) and guess the condition of the plant.

- Directly measure plant condition as well as the environment.

Why make guesses about plant condition when it so easy to make direct measurements?

1.5.3 Instrument Requirements

PLANT TEMPERATURE IS THE KEY TO PLANT CONDITION.

Instruments designed to measure water stress should:

1. Measure canopy temperature accurately. Plant temperature is the key to understanding plant behavior. Everything that a plant does is controlled by the temperature of the plant. While we do not understand everything there is about plant temperatures, we do understand that plant Temperatues can be "below normal", "normal" and "above normal." It only makes sense that plant temperature measurements be as accurate as possible.

2. Be portable. this would allow measurements to be made anywhere that is desired. The instrument must not weigh too much or be too clumsy to use.

3. Be rugged and sturdy for use in the field. Any piece of equipment used in the field is exposed to jarring, bouncing, hot and cold temperatures, and dust (among other things). Many "laboratory quality" instruments would be destroyed by the way farmers would handle them. If it isn't rugged, don't use it in the field.

4. Allow for multiple readings in the field.
The reason is simple : fields are variable.
One section may have a heavy soil, another section may have salt problems. One sample of one plant is a poor representation of the overall average. It must be possible to sample many plants in order to have confidence that the reading represents the true average.

5. Be simple to use. No matter how good it is, if it isn't simple to use, most growers will not use it.

6. Correlate well with physiological measurements.
Instrument readings must make sense. The instrument must be designed to provide information which relates directly to the condition of the plant. This means the scientific basis for the instrument must be strong.
The Scheduler design fulfills these requirements.

1.5.4 Scheduler^{R} Hardware Features

- Aspirated air temperature and humidity sensors.

- Infrared thermometer

  Distance: one inch to infinity
  Range: $\pm$ 108^{o}F from ambient
  Field of view: 8^{o}
  Spectral response: 8-14 um
  Accuracy: $\pm$ 1.0^{o}F
  Repeatability: $\pm$ 0.4^{o}C
  Emissivity: 0.99
  Operating distance: 1 inch to infinity

- Ambient temperature

  Range: 32^{o}F to 140^{o}F
  Accuracy: $\pm$ 1.0^{o}F
  Resolution: 0.2^{o}F

- Humidity

  Range: 0 to 100%
  Accuracy: $\pm$ 5%

- Solar Radiation:

  Range: 0 to 100 mW/cm^{2}
  Accuracy: $\pm$ 10%

- Response Time:

  Screen update < 2.0 seconds
  Sample frequency < 0.5 seconds

- Microprocessor: 64-K -- 8 bit.

- Display: 2-1/2 X 1-1/2 LCD on processor

  1-1/2 X 1 inch on sensor gun

- Serial Interface:

  RS-232 25 pin male connection
  Baud Rates: 50-2400 (selectable)
  Character Sizes: 5-8 (selectable)
  Other download parameters also selectable

- Softside carry case.

- Warranty: 1 year

- Power -- 6 C cell batteries, with an expected life of 20 operating hours.

- Recharging port provided for use with rechargeable batteries.

CHAPTER 2 - SAMPLING TECHNIQUES

2.1 Guidelines

The major concerns in sampling are :

1. **Operating a clean unit.** Use in dusty conditions requires clean the cleaning of the lens of the infrared thermometer. When the lens becomes dirty, the temperature readings are lower than they should be. This results in index readings lower than they should be. The instruction manual will give you complete instructions.

2. **Adjusting to ambient conditions.** If the sensor gun is stored in a cold office, or a hot truck, the air temperature reading may not be accurate, even after the 94 second cound-down. Some common sense must be applied to allowing the gun to adjust to the outside. This is very important in the first 10-15 minutes of operation.

   One technique used to insure the gun has adjusted is to stand in one spot and take multiple samples. When you obtain index averages, from 3 separate samples, that are within 0.5 stress units, the gun is adjusted.

3. **Time of day.** The user should be consistent with time of day. He should return to measure the same field at about the same time each day.

4. **Proper aiming technique.** The steps to aiming properly are:

   a. Keep the sun at your back.

   b. Keep the gun 3 feet above the soil. When soil is hot and dry, it heats the air near the surface and affects the index readings.

   c. Select a target that avoids soil, sky, shadows, wood, or anything that is not green, sunlit vegetation.

      - Aim at individual leaves.

      - Aim down the row (refer to the chart on spot size to make sure you don't aim too far down the row, especially when bare soil is between the rows).

- Make your own sampling surface if necessary. On small leafed crops, for example pecans, it may be necessary to "bunch" leaves to create a surface of sunlit leaves to sample.

d. Aim at the crop at least 2 seconds before squeezing the trigger. This insures that you do not accidentally enter erroneous data.

e. Do not aim more than about 30 feet from the point you are standing. Remember, when you aim at a target 30 feet away, you are really seeing a target that is about 4 feet wide and 270 feet long.

5. Sampling spot. One of the keys to interpreting the stress index readings is the trend of the index (is it increasing or decreasing with time?). This makes it important for a user to sample the same spot on different days.

6. Has the user selected spots which make sense in terms of his irrigation system? With an effective sampling scheme, there will be sufficient time to collect data on most farms.

7. How does the user treat the instrument between fields? After he samples one area, and is traveling to the next, what happens to the sensor gun? The "nose" of the gun should NOT be placed back in the holster. A good travel technique during a sample session is to place the gun upside down in the holster. The fan SHOULD remain on at all times. This is not the time to worry about battery life. Your concern at this point is accuracy. Air conditioning (for 5-10 minutes) should not affect the accuracy of the sensor head.

8. How much abuse is the sensor gun, especially the coiled cord, receiving? Cord failures can occur in units in which the cord is twisted, knotted and yanked on. Symptoms of a broken cord are:

- Software locks up (caution, the software can lock up in the R&D models if one of the computer parameters is accidentlly changed. Check to make sure XON/XOFF is DISABLED.

- Sensor readings become wild (canopy temperature of 300 degrees or relative humidity of -1000% , etc.)

9. Do not take an excessive number of data points in one spot. In spite of its great number collecting ability, all you need is about 10-15 shots per location.

10. Stable sunlight. The sunlight sensor on the

Scheduler is designed for relative readings. The highest reading you obtain on one unit may be an 85 while a different unit may read 95. The reason for the measurement is to allow a user to decide:

- Was the reading near maximum (it should be), indicating a clear day and sufficiently strong sunlight?

- Were the readings stable? When you examine a print-out, the solar readings should be within about 10-15 units of each other. If the spread is greater than this, it may indicate the data was taken under partly cloudy skies, too early or late in the day, or the user was simply casting shade on the back of the gun with his body. You should ignore the solar readings when:

- You are sampling trees, the solar sensor was designed assuming the "nose" of the gun was pointed slightly down.

- Winter-time. The Scheduler is not used by many during the winter months. The sunlight sensor is inconsistent when the sun is at winter-time elevations. The other sensors are not affected.

2.2 Time of day

If you have 1 hours worth of data to take, the best time to start would be 90 minutes after solar noon. Try to arrange the customers sampling so that all samples can be taken in 1 hour. It's surprising how much acreage can be sampled in an hour once the irrigation scheme on a farm is understood.

If you have 2 hours worth of data to take, then start 30 minutes after solar noon. The index may change some during this time, but should not be a serious concern.

If you have 3 hours worth of data to take, then start 30 minutes before solar noon. There may be a noticeable change in the index between the first and last samples, depending on how much the air temperature changes.

If a user absolutely feels that he cannot make readings between solar noon and the two hours afterward, then he must be reminded to :

- Be consistent. Always sample the same area at the same time of day.

- Do not compare index values taken at 11:00 with index values taken at 2:00. They will probably be different. Refer to figure 1 to see the normal daily index pattern.

In some areas, clouds may develop in the afternoon. This means that the environment becomes more moderate. The best time to start sampling in such areas is about 1 hour before clouds usually start developing.

CHAPTER 3 - DATA ANALYSIS

3.1 What is Data Analysis?

In the most unscientific sence, it is the scheme for evaluating the results of field sampling.

3.2 Data Quality Control

Is the crop temperature data acceptable?

One key to deciding if crop temperature data is acceptable is to examing the STD, or standard deviation value. STD is a measure of how uniform the canopy temperature samples were. Some variability is expected, and some can be caused by stress, but STD should be within normal limits (2-4^{o} F). We have found that even researchers who have 2-3 years experience with the Scheduler periodically store samples which have STD values which are unacceptable.

It is more difficult to answer this question in the PRODUCTION models, since there is no room in the software for calculating STD. One indication of improper sampling will be a canopy temperature average that is very different from the others. You must be careful about using differences in averages, however, since this is exactly what you are looking for.

Is the air temperature data acceptable?

This can be decided by looking at a graph of air temperature versus time. If the user has a clear pattern in his air temperature data (increasing or decreasing with time) it probably indicates the sensor gun was either too hot or too cool. Patterns in the air temprature data can invalidate part or all of a data set.

Were effective sampling techniques used?

This is a judgment call. Chapter 2 should be studied and thoroughly understood. If you are confident in the sampling, and the data do not indicate a problem, then proceed.

3.3 Key Facts to Remember

The following facts apply to the leaves of most crops. Keep these facts in mind as you respond to individual questions from growers.

- Young leaves are cooler than old leaves in some crops and warmer than old leaves in other crops.

- Individual leaf temperatures constantly fluctuate around an average value.

- Leaves can wilt when stressed or non-stressed. Plants that are wilted, but have adequate soil moisture, will be cooler than wilted plants that are moisture stressed.

- Stressed leaves can be up to 20^{o} F hotter than non-stressed leaves.

- Non-stressed leaves are generally cooler than ambient in most crops.

- Stressed leaves are generally above air temperature.

- Measureable increases in leaf temperature occur 1 or more days before visible wilting occurs.

- Differences in temperature between stressed and non-stressed plants are directly correlated with differences in their transpiration rates.

- Plants growing in saline soil may be much hotter than plants growing in non-saline soil.

- Leaf temperatures of different varieties may differ by 2-4 F under the same soil moisture conditions.

- Differences in yields are associated with differences in leaf temperatures.

CHAPTER 4 - DOWNLOADING TO A P.C.

If there's one problem you don't need when you're showing the Scheduler to a grower, its trouble with his p.c. You haven't got the time, nor the interest, in becoming a computer expert (but the grower will think you should be one). So what should you do?

As it turns out, it's relatively easy to solve most of the problems you will encounter. Let's take them 1 by 1.

4.1 Testing the Grower's P.C.

Problem #1. Does the customer's computer have the necessary hardware? The necessary hardware is called an RS-232 port. Have you ever looked on the back of a computer. There can be all sorts of things back there. And none of them marked. So now what? Simple. Do this:

1. Turn the computer on.

2. If a C> appears on the screen, then type "A>" (without quote marks) and press the ENTER or RETURN key.

3. Now that you have an A>, place the Scheduler support analysis disk into the A drive.

4. Next, type the word "MENU" (without quotes) and press the ENTER or RETURN key.

The program will present you with its main menu. Press "U" to select utilities

The utilities menu has two options :

1. Test the growers's computer.
2. Import test file.

Select option 1. The program will automatically test the computer. You will see a screen that looks like this:

Status According to RAM

Total Memory	640 Kbytes	Disk Drives	2
I/O Memory	2 Kbytes	Parallel Ports	1
Sys-Brd Mem	64 Kbytes	Serial Ports	2
Video def	80 X 25 color card	Game adapter	YES

The ansers will be different for every computer.

If the grower's computer has the necessary hardware, you will then see this sentence:
"According to RAM, you have 1 (or 2) RS-232 ports"

The program will automatically take you to the next step.

If the grower's computer does not have the necessary hardware, you will see this sentence:

"According to RAM, you cannot down-load a Scheduler to this P.C. An RS-232 card must be installed".

The program will then return to the main menu.

Problem #2. Now that you know the grower has 1 or 2 RS-232 ports, how do you find it? There are two rules:

1. The port has either 9 pins or 25 pins.

2. The port has male pins. Computers also have 25 pin female plugs which are used to connect the computer to a printer. A 25 pin female connector will not usually work. (Radio Shack is one brand which uses female RS-232 plugs).

You'll have to find these yourself. Just follow the two rules above. If neither of these tests work, give us a call.

Problem #3. The computer has a 9 pin male RS-232 port, but the Scheduler comes with a 25 pin male plug. All you do is put an adapter between the Scheduler plug and the computer. You should always carry two types of adapters with you:

1. 25 pin female-female adapter.
2. 9 pin to 25 pin female-female adapter.

By this time, you should have been able to learn that the computer should work and make the necessary physical connections.

Problem #4. Is the COM port the Scheduler is hooked up to called COM 1 or COM 2? Who cares anyway? Well, it's an unfortunate computer fact, but you have to learn the answer to this question. The TEST program makes this easy, too.

At this point, the program will take you step by step through the COM port identification procedure. All you'll need to do is answer a few questions which the program will ask and also insert a special RS-232 tester between the Scheduler and the computer (these are available from many sources for between $ 7 and $15 each).

At this point, you will be ready to down-load a Scheduler into the computer. The program will automatically return you to the main menu.

THE CARBORUNDUM COMPANY

1989 SCHEDULER TRAINING

CHAPTER 1 - CWSI THEORY

1.1 A Simple Principle

CWSI (crop water stress index) is based on a simple principle. Any surface which is evaporating water at a high rate will be cooler than a similar surface that is not evaporating water as fast. You have probably experienced this principle many times. Recall a summer day at the beach. Before diving into the water, the summer sun made your skin feel warm. After you emerged from the water, you felt much cooler. Why? Simple. Your skin was evaporating water much faster when it was wet than when it was dry.

In a similar fashion, a leaf that is supplied with adequate water (non-stressed) will evaporate water faster than a leaf that has inadequate water (stressed). The result will be a difference in temperature between the non-stressed and the stressed leaves.

Back to the beach. If you felt too hot at the beach, you had two options to cool down, first, you could jump into the water, second, you could just walk into the shade. Isn't it amazing how much cooler you feel standing in the shade than when standing in the sun?

Plants react much the same way. Whenever a cloud moves in front of the sun, their temperature will also decrease. This means that whenever we want to compare stressed and non-stressed plant temperatures, we must be careful to make that comparison under the same sunlight conditions. It makes no sense to compare the temperature of a leaf in the shade with a sunlit leaf. The sunlit leaf will always be hotter. (Have you ever felt hotter in the shade than in the sun?)

1.2 Plant Temperature Research

Many scientists have studied plant temperatures during the last 150 years. A few were able to capture and understand the relationship between the plant's temperature and its overall health. Accurate temperature measuring devices were needed to advance the practical use of plant temperature. Only during the last 10 years were the first reliable hand-held infrared thermometers manufactured and commercially available to advance the use of this technology. Following is a summary of the major facts which have been reported.

1875 -- Thin leaves are cooler than thick leaves.

LITERATURE SUMMARY

Relationship of Leaf and Air Temperature

Lomas et al. (1971) stated that the relationship of leaf temperature (TL) to air temperature (TA) was dependent on weather and soil moisture conditions. They observed that moisture stressed potato leaves were 7-9 C warmer than air temperature.

Lange (1965) identified five important factors affecting the difference between leaf and air temperature (in order of relative importance): (1) net radiation (sunlight intensity and stability) (2) transpiration rate (stress status) (3) convective heat exchange with the surrounding air (windspeed). (4) the exchange of chemical energy within the plant. (5) heat exchange due to water exchange within the plant.

Linacre (1964a) examined representative leaf temperature versus air temperature data for non-stressed plants. He theorized that in sunny moist climates the cross-over point -- the point at which leaf and air temperatures are equal -- is about 33 C. Field research by others suggest that leaf and air temperatures may be equal over a fairly broad range of ambient conditions. Mid-day cross-over points between 23 and 34 C have been observed in cotton, corn, alfalfa, sorghum and soybean (Palmer, 1965; Blad and Rosenberg, 1976a; Steinmetz, 1977).

Early morning leaf temperatures of corn, alfalfa, sorghum, soybeans and grass have been observed to be nearly equal to or cooler than air temperature in Nebraska (Blad and Rosenberg, 1976a; Steinmetz, 1977) in Australia (Palmer, 1965) and in Arizona (Ehrler and van Bavel, 1967; Ehrler, 1973). Leaf temperatures increase more rapidly than air temperature during the morning hours, resulting in less negative values of dT (dT = TL - TA during that period. By mid-morning, the energy balance shifts and dT starts becoming more negative. By mid to ate afternoon dT is generally at its most negative value (Palmer, 1965; Stone et al., 1975; Blad and Rosenberg, 1976a; Steinmetz, 1977; Sumayao et al., 1977). Gates (1968, 1969, 1973) published data showing that dT ranges from -8.9 C to +21.5 C, depending on plant species and ambient conditions.

dT has been related to decreasing soil moisture content in potatoes (Lomas et a., 1971); cotton (Bartholic et al., 1972) and sorghum (Sumayao et al., 1977; to lower leaf-water potential in cotton and wheat (Bartholic et al., 1972; Ehrler et al., 1978a, b); to reduced transpiration in potatoes (Lomas et al., 1971), sorghum (Sumayao et al., 1977) and wheat (Jackson et al., 1977); and to increased vapor pressure deficit (Ehrler, 1973).

Factors Affecting Leaf Temperatures

Leaf temperature is a function of air temperature, radiation intensity, wind velocity, leaf dimension, leaf thickness and the angle of leaf orientation with respect to impinging radiation (crop geometry) (Ansari and Loomis, 1959; Thofelt, 1975). Other important factors are transpiration, vapor pressure deficit (Ehrler and van Bavel, 1967 ;Wiegand and Namken, 1966) and leaf position on the plant (Waggoner and Shaw, 1952).

Wiegand and Namken (1966) showed a linear relationship between solar radiation and leaf temperature. Wiegand and Swanson (1973) reported that cotton leaves require 30 seconds to 1 minute to reach a new equilibrium temperature when solar radiation intensity changes. Stone et al. (1975) observed changes in sorghum leaf temperatures of up to 3 C with fluctuating solar radiation.

Plant Responses to Moisture Stress

Hsaio (1973) summarized the observed plant responses to water stress, which include reductions in the transpiration rate, CO_2 assimilation and respiration rate, cell size, plant-water potential, growth rate, total protein synthesis and stomatal aperture diameter. Increases occur in leaf temperature, mesopyll resistance and total free amino acids. He stated that these responses to moisture stress seem to represent general patterns of modulation in plants under adversity. He concluded that the effects of water stress must be evaluated in terms of the severity and duration of the stress and of the plant species involved.

Stomatal Response

Ehrler and van Bavel (1967) stated that the regulation of transpiration by the leaf stomates is of specific importance to water use and its efficiency in crop production. They indicated that as leaf water deficits develop, stomates close, leading to decreases in transpiration and increases in leaf temperature.

Clark (1973) stated that stomatal resistance in peas increased as moisture stress developed, resulting in increased leaf temperatures. He concluded that the status of water in plants represents an integration of the atmospheric demand, soil-water potential, rooting density and distribution and other plant characteristics. He stated that, for a true measure of plant moisture stress, measurements should be made on the plant instead of the soil or atmosphere.

Vegetative Growth and Yields

The effect of moisture stress on vegetative growth and yields depends on the degree of stress and on the state of growth at which stress occurs (Somerhalder, 1962; Sionit and Kramer, 1977). Denmead and Shaw (1960) observed that stress in corn during silking was more harmful to grain yields than stress during any other growth stage. They suggested a possible tendency for recurring periods of stress to have increasingly smaller effects on yield.

Sionit and Kramer (1977) showed that soybeans stressed at different growth stages responded differently in terms of yield and of oil and water content of their seeds. Moisture stress was most detrimental when it occurred during pod formation and filling. Relcosky et al. (1975) theorized that a physiological change occurs in corn during pollination which makes the interpretation of leaf water potential measurements after that stage difficult.

The Measurement of Water Stress

Kramer (1963) listed five desirable characteristics for any method used to measure moisture stress: (1) the measurement should correlate well with rates of physiological processes; (2) the method should produce similar results when used on a wide range of plant material; (3) the technique should be applicable to soil; (4) the method should be simple and inexpensive and (5) the method should require a minimum of plant tissue for measurement. Scheduler index readings are directly related to transpiration rates (criteria 1); are useful on a wide range of plant material (criteria 2); relate to soil moisture deficits (criteria 3); are simple and inexpensive to make (criteria 4) and require no plant tissue for measurement (criteria 5).

Measurements of Leaf Temperature

Moisture stressed leaves have been consistently reported as being warmer than non-stressed leaves. Reported differences between stressed and non-stressed leaves for various crops range from 5 to 24 F .

Tanner (1963) suggested that the temperature difference between stressed and non-stressed potato leaves was a qualitative indication of transpiration differences. He concluded that, with a better understanding of transfer processes at the plant surface, leaf temperature measurements could provide quantitative data on plant water status. Since Tanner's article was published that understanding has been acquired.

Ehrler (1973) stated that leaf temperature measurements are an indirect indication of stomatal behavior. Ehrler et al. (1978a) demonstrated that canopy temperature in wheat increased as plant water potential decreased. Differences in canopy temperature between stressed and non-stressed wheat plants were shown to be a reliable indicator of plant moisture stresses.

Instruments which measure leaf temperature should fulfill four basic requirements: (1) the radiation balance of the leaf should not be disturbed; (2) the real temperature of the leaf should be measured with sufficient accuracy: (3) it must be possible to take repeated readings with the instrument and (4) the instrument should be transportable and sturdy enough for use in the field (Lange, 1965). The Scheduler fulfills these requirements.

Managing Irrigation using Plant Temperatures

Ideally, the plant should signal when to irrigate and the soil should indicate how much water to apply (Teare et al. 1974). Aston and van Bavel (1972) and Nixon et al., (1973) suggest that large canopy temperature variability within a field should signal the onset of soil moisture deficits due to the non-homogeneous moisture retention properties of large fields. Ehrler (1973, 1978b) showed that the leaf-air temperature differential could be used to signal the need for irrigation. Ritchie (1977) suggested using the temperature difference between stressed and non-stressed plants to detect the occurrence of soil moisture deficits.

Brown and Rosenberg (1973) defined a model to estimate evapotranspiration (ET) using crop temperature. Hourly estimates of ET were within five percent of energy balance estimates. Daily estimates of ET over alfalfa were within 10 percent of estimates made by energy balance (Blad and Rosenberg, 1976b).

Jackson et al. (1977) developed an expression for relating ET to net radiation and crop temperature:

$$ET = Rn - B(Tc-Ta)$$

Tc is crop temperature, Ta is air temperature Rn is net radiation and B is a calibration coefficient.

Canopy temperature measures have been used to estimate ET rates in sugarbeets and cotton (Brown and Rosenberg, 1973); sorghum,soybeans and millet (Stone, 1974; Hellman et al., 1976); alfalfa, beans and grass (Idso et al., 1977) and wheat (Jackson et al., 1977).

Jackson (1982) summarized the history of infrared thermometry and described a USDA method of quantifying water stress. The index he describes is known as the Crop Water Stress Index or CWSI. CWSI is defined as:

$$CWSI = (Tc - T\,min)/(Tmax - Tmin)$$

where: Tc = measured canopy temperature
T min = minimum canopy temperature for a given set of meterological conditions
T max = maximum canopy temperature for a given set of conditions. Experimental data is presented which shows that CWSI is strongly related to soil moisture content in wheat. This index is the basis for the index used in the Scheduler.

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1905 -- Sudden increases in wind speed causes a decrease in plant temperature.

1915 -- The leaves of evergreens are much hotter than the air during winter (that's how they survive and photosynthesize).

1923 -- USDA researchers in Arizona showed that healthy leaves of various crop plants are cooler than the air during mid-day.

1929 -- The USDA confirmed that healthy cotton leaves can be 8 F or more cooler than the air.

1938 -- Garden plants can be as much as 14°F below air temperature.

1052 -- The temperature of tomato and potato leaves are nearly the same.

1962 -- A scientist developed equations which showed that if a leaf remains motionless while the wind blows, its temperature is controlled by the windspeed, but if the leaf flaps, water evaporation controls leaf temperature.

1966 -- Infrared thermometers were first used to measure leaf and canopy temperature. The importance of solar radiation and time of day was emphasized.

1971 -- Leaf water content is correlated with leaf temperatures and relative humidity.

1973 -- Leaf water potential, stomatal resistance and leaf-air temperature differences are all correlated.

1973 -- A USDA scientist suggested using leaf-air temperature differences to schedule irrigations.

1981 -- USDA scientists developed the crop water stress index (CWSI).

In 1984, Standard Oil Engineered Materials Company (The Carborundum Company) conducted the first large scale field test of the CWSI concept. Prior to that time all the research had been conducted on small plots. Standard Oil Engineered Materials has been the driving force behind the technology transfer of CWSI from the theoretical domain of research scientists to the practical world of growers.

1984 -- First field test of CWSI concept.

1985 -- Multi-state field tests of CWSI.

1986-1988 -- Field tests continue. Simultaneously, the marketing/commercialization of the Scheduler was begun.

Between 1978 and 1988, the literature has exploded with information which demonstrates that canopy temperatures can be used to schedule irrigation and monitor crop condition on a wide variety of crops.

Standard Oil Engineered Materials has collected CWSI information from over 125 separate locations (experiments and grower fields). No other infrared thermometer company has been involved in CWSI research of this magnitude. We have conducted more CWSI research than the combined efforts of several university research departments.

The Scheduler is a new tool which helps answer questions that could never be asked prior to its invention. Plants are amazingly complex in their behavior and some questions will take years to answer. The important point is that sufficient knowledge exists to allow growers to benefit from monitoring the condition of their crops.

Points to Remember

- **Non-stressed leaves are usually cooler than the air.**
- **Plant temperature is related to plant health. A plant that is "stressed" will (when the sun is shining brightly) will be hotter than a healthy "over-stressed" plant.**

Do not be afraid to ask questions. Once you master the basics, you will start to feel comfortable with the Scheduler.

1.3 Important Scientific Conclusions

The following statements summarize the conclusions of agricultural scientists concerning plant temperatures during the period 1929 - 1988. There is little room for doubt that leaf temperatures are considered very important.

"The facts suggest that the differences in yields are associated with the observed differences in their leaf temperatures." (Eaton and Belden, 1929).

"...transpiration invariably tends to lower the temperature of the transpiring leaf...." (Curtis, 1936).

"Leaf temperature relative to air temperature can be predicted..." (Waggoner and Shaw, 1952).

"Thus a sensitive measurement of the temperature difference between plant samples may provide an indication of transpiration differences." (Tanner, 1963).

"The temperature differences between well-watered and stressed crops should indicate a relative need for irrigation. Within large irrigation projects it should be possible to identify fields needing irrigation from crop canopy temperature information. Within individual fields plants in areas not irrigated adequately should stress sooner and have a higher canopy temperature than the nonstressed plants in well-watered surrounding areas." (Bartholic et al., 1972).

"On a given day, relative leaf water content and leaf temperature were highly correlated." (Carlson et al., 1972).

"Field studies at this laboratory have shown Tc-Ta to be a sensitive guide to changes in stomatal aperture, as measured by leaf resistance." (Ehrler, 1973).

"...measurement of Tc-Ta still appears adequate for assessing soil water status effects on crop vigor and signalling needed irrigation ..." (Idso and Ehrler, 1976).

"The results indicate that the temperature differences between the stressed and the unstressed plants arises primarily from differences in transpiration. It is further suggested that after proper calibration, plant temperature promises to be a reliable index for identifying crop water deficits and for optimizing irrigation scheduling." (Sandhu and Horton, 1978).

"The results of this experiment suggest that knowledge of leaf and air temperatures, which are relatively easy and inexpensive to determine, can be useful in assessing the water status of corn and sorghum." (Sumayao et al., 1980).

"The results demonstrate the ability of surface temperature measurement by means of infrared thermometry to rapidly assess large areas of cropped land for plant water potential depressions arising from shortages of soil moisture." (Idso et al., 1981)

"We conclude that canopy temperature variability can be used to signal the onset of plant water stress...." (Clawson and Blad, 1981).

"...canopy temperature data can be used to track crop water stress and the effect of stress on yield...soil factors indicate when plants may be stressed, plant factors indicate when they are stressed. Plant factors, such as water potential, are point measurements that require numerous samples to characterize a field. Canopy temperature measurements can minimize this problem." (Jackson, 1982).

"...linear regression analysis indicate close correlation between water stress index...and water potential..." (Tormann, 1986)

"The Infrared Thermometry device as represented by the "Scheduler" ...is a very sensitive and yet practical means of determining the water stress status of a crop such as vines. The neutron probe while quite accurate in its evaluation of soil moisture content did not provide any measurement of stress...The IRT device is as sensitive to plant stress as the porometer while more simple to operate and maintain than the other devices discussed above...if a known, unstressed vine is used as a reference and the indexes for the vines in question for that date are compared with the reference vine then the IRT method can be used very well for stress management." (Krauter, 1988).

****

The Scheduler is based on very sound physical and scientific principles. Those who learn to use it first will be the furthest ahead.

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Points to Remember

- **Plant temperatures can be used to indicate plant stress.**
- **Higher than normal plant temperatures results in yield and quality losses.**
- **The hotter a plant is (relative to air temperature), the lower its transpiration rate.**
- **In the field environment, plant temperature variability is a sign that stress has <u>just begun</u>.**

1.4 CWSI Theory

1.4.1 Definition of the Index

Think of the stress index as a percentage. You use percentages all the time. For example, sales commissions are often expressed as a percentage. A salesman wants this percentage to be as high as possible. But, what what kind of stress index reading should you want? Let's compare the index to a sales commission.

$$\text{percent profit} = \frac{[\text{sales commission}]}{[\text{retail price}]} \times 100$$

All your percentages are scaled between 0 and 100 % because you multiply by 100.

similarly,

$$\text{stress index} = \frac{[\text{actual stress}]}{[\text{possible stress}]} \times 10$$

All the stress index percentages are scaled between 0 and 10 because we multiply by 10.

If we could perfectly estimate the actual and possible stress (we can't) then the following chart would be true:

Index		
0	=	no stress detected
1	=	10 % of possible stress
2	=	20 % of possible stress
3	=	30 % of possible stress
4	=	40 % of possible stress
5	=	50 % of possible stress
6	=	60 % of possible stress
7	=	70 % of possible stress
8	=	80 % of possible stress
9	=	90 % of possible stress
10	=	100 % of possible stress

1.4.2 Calculating the Index

At this point, you're probably thinking "O.K., I can understand that much. But how do you measure 'actual stress' and 'possible stress.'" It's not really very complicated. In fact, it's really very easy. You can calculate an index without using a computer, equations or anything fancy. All you need is some information. What information? All you need to know is:

- air temperature
- relative humidity
- plant temperature

The next step can be done by almost anyone: subtract air temperature from plant temperature. For example, if air temperature is 100° F and plant temperature is 95° F, then 95 - 100 = - 5. The plant canopy is 5 degrees cooler than the air.

Let's do that again, but this time use a simple equation:

Diff = Tc - Ta — Tc is just the plant temperature (or temperature/air) and Ta is just the air temperature. Let's put the numbers in.

Diff = 95- 100

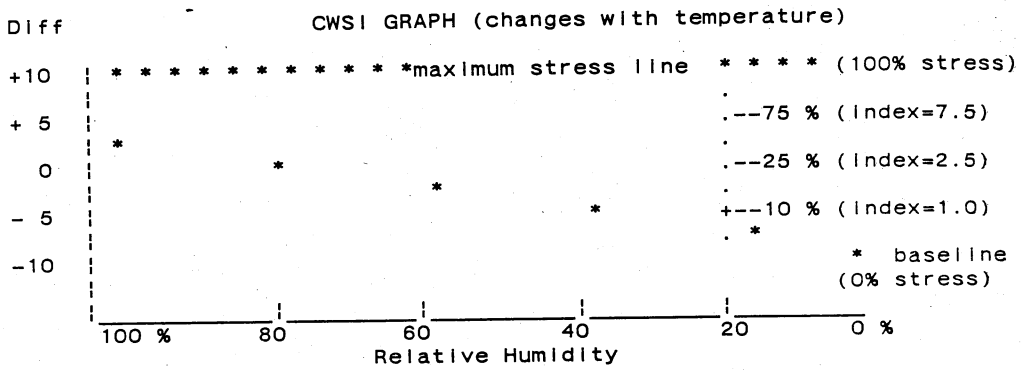
Diff = -5 — Now we have a name for the number. The name is Diff, which stands for "the difference in temperature between a plant and the air temperature", (or the delta temperature

That's it. The information isn't mysterious. It's very simple. The math isn't hard at all.

Points to Remember

- **The information you need to know to calculate an index is simple. Every one is familiar with air temperature and relative humidity. Plant temperature is the only new piece of information.**
- **The math is very simple**

Now that you know the plants are 5 degrees cooler than the air, and suppose the relative humidity is 20%, just look at a graph like the one below:



This graph is not very complicated. The vertical axis is where we find the value of Diff (remember that subtraction we had to make ?). The horizontal axis is where we look up the relative humidity.

Ready? Let estimate the Index for Diff= -5 and Humidity = 20%

First we just look on the vertical axis for the -5 then draw a line from left to right all the way across the graph. Next, look on the horizontal axis and find the 20. Now, draw a line from the 20 to the top of the graph. The two lines you draw will make a + somewhere. The + is where our sample data fits between two other lines.

Now, study the graph. Note that our sample data point is about 10% of the distance between the baseline (0% stress) and the maximum stress line (100% stress). Since our data point has traveled only 10% of the maximum possible distance, we say the Index is 1.0.

What would the Index be if Diff = + 5 and relative humidity was still 20%? (correct answer is 7.5).

Please note, the horizontal axis in the real Index calculation is not strictly determined by the relative humidity but rather a combination of humidity and temperature called the Vapor Pressure Deficit (VPD).

1.4.3 Definition of a Baseline

It wasn't hard to calculate an Index was it? All we needed was 3 pieces of information and a simple graph. But graphs like the one you used in the sample are not found just anywhere. How is a graph like this made?

The Index graph has two lines on it. The baseline is the line which shows us what the normal Diff (remember what Diff is?) value is for a healthy crop. The maximum stress line shows us what the highest Diff value is for a very sick (but still alive) crop. The basic process of making this graph is simple.

First, we use the Scheduler on healthy and stressed areas of a particular crop for as much of the season as we can. If we can collect data for more than one season, or in more than one location, so much the better. Two mathematical equations are then developed which effectively summarizes all this information, so that we can use it in a computer. One equation is called a baseline. The other equation is called the maximum stress line. The baseline represents 0% stress (or an Index of 0). The maximum stress line represents 100% stress (or an Index of 10). If the Index was perfect, the Index would never be less than 0 or greater than 10. In practice, the Index will often be less than 0 and can exceed 10.

Equations have been developed for a number of crops, including:

Alfalfa, almonds, apples,asparagus, barley, cantaloupe, carrots, corn, cotton, cucumber, grapes, green beans, grapes, Jojoba, pecans, potatoes, sorghum, soybeans, sugar beets, tomatoes, watermelon, wheat.

Equations cannot be developed for some crops. For example, the leaves of lemons and oranges are thick and waxy. They evaporate water slowly at best. There is no consistent difference in temperature between stressed and non-stressed leaves for these crops. This makes any equation developed unreliable for these type of crops.

It is not essential to have a set of equations developed for a particular crop. General purpose equations called "HIGH" and "LOW" have been developed for use on crops other than those listed above. "HIGH" is used on plants with slow transpiration rates and "LOW" is used on plants which are high consumers of water. These equations will probably not produce a typical 0 to 10 scale. Instead, the customer will need to use them for a while to learn what to expect. But at least he will be able to get started.

1.4.4 Negative Index Values

When we calculate an Index, we compare the actual temperature of the crop (measured with an infrared thermometer) with our baseline. If the actual temperature

of the crop is less than our baseline predicts, it means that the crop is cooler than expected. The index will be negative. It is normal to find that measured values of the index are 1 to 2 units below our baseline, i.e., the stress index will be -1 to -2. If the index is more negative than -2, possible explanations are:

- The crop is exceptionally cool, could be wet from rainfall or irrigation or simply using an excessive amount of water. Negative index values are correlated with low pressure chamber readings.

- The sunlight intensity was too low. This can happen quite easily. Mistakes which can cause negative index values include:

  . Clouds in front of the sun. On a cloudy day, the plants are under much less stress than on a sunny day. The manager is concerned about the maximum stress plants exhibit, not the minimum. All measurements must be made with bright sunlight on the plants.

  . Too early or too late in the day. This may not be so obvious, especially if it has been a hot day and the air temperature is still high. The "window of opportunity" is longer during the summer than in the winter. Learn when solar noon occurs in your area. Reference all recommended sampling times to solar noon.

  . There is an error in the baseline. Once we have used a baseline for a while, baseline errors should not be significant. It is not hard to become accustomed to using a baseline that has an error in it. For example, the current tomato baseline consistently reads negative on healthy plants. Irrigation is needed when the index reads about 0 on tomatoes. We could adjust the baseline, but since we have learned how to use the current one, there is no need. In fact, it would confuse current users.

  . You aimed at the shaded part of the canopy. We strongly recommend you keep the sun at your back as a standard practice. This insures you will be looking in the direction of the maximum number of sunlit leaves. This is not necessary on some crops (such as alfalfa) but is always good practice. Make it a rule.

  . You aimed too far from the point where you were standing and included the sky in your measurements. This problem is avoided by using proper aiming techniques.

  . Air temperature is unusually cool, but the sunlight is bright. In this situation, the crop is also unusually cool, producing a negative index. There is nothing that can be done about this situation. There is also nothing to worry about from a water stress viewpoint. The index is right: the crop is not too hot.

  . The sensor gun was too hot. The gun may have been left in a hot truck. If this happens, be sure to allow plenty of time for the instrument to cool off.

Points to Remember

- **Clear skies and time of day are critical considerations.**
- **Negative index values are normal.**
- **Negative index values indicate no stress.**
- **Mistakes can artificially create negative index values.**

1.4.5 Positive Index Values

The agronomic interpretation of positive index values may be different for each crop. For example, cantaloupes is a crop on which you want only small positive index values (0-1). Cotton can tolerate moderately positive index values (2-3) without any damage. Seed alfalfa requires large positive values (7-9) to produce seed. For this reason, we have written a series of KNOW-HOW bulletins to explain what we currently know about interpreting index values for a particular crop. These bulletins are revised as new information becomes available.

Positive index values occur for two reasons:

1. Because the crop is hotter than the baseline predicts.

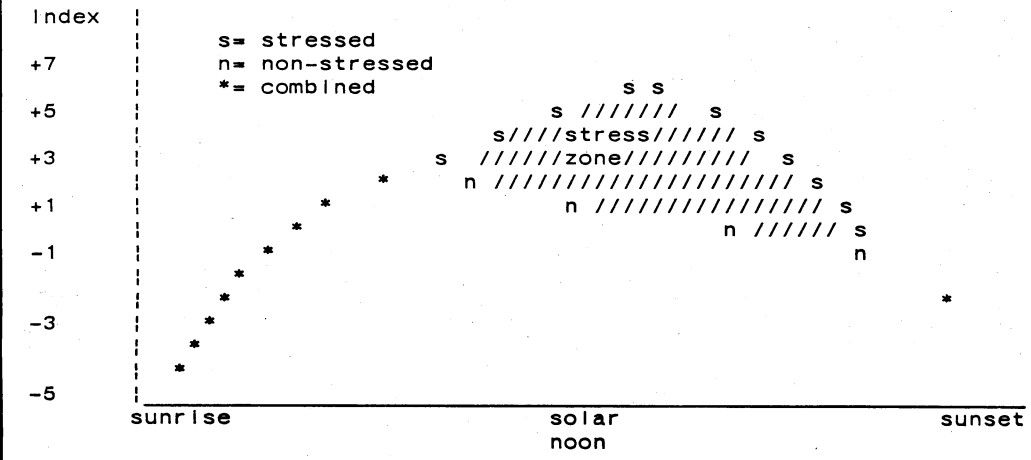
2. The sensor gun is cold. If the gun is stored in a cool room and then taken outside on a hot day, the index values will be too high for the first few minutes.

The index can be greater than 10. There are two reasons why. First, bare soil can influence the index. If you aim so that some soil is measured, the index could exceed 10. Second, we are purposely conservative in how we estimate the maximum stress line. This allows us to give greater sensitivity to the index. Severely stressed crops may exceed 10.

1.4.6 Index Trends

Hourly Trends

The index is not constant from hour to hour. It varies with the sun. The graph below shows the expected hourly pattern for a stressed and non-stressed crop.



You should already know about sunrise and sunset, but what in the world is "solar noon?" In the Old West, another name for solar noon was "High Noon." Solar noon occurs when the sun is exactly half-way between sunrise and sunset. The sun is brightest and hottest at this time. Solar noon can occur anywhere between 12:00 p.m. and 2:00 p.m., depending on where you live and whether or not you are on daylight savings time or standard time. The easiest way to determine solar noon is to use the old Boy Scout trick of placing a stick in the ground. When the shadow of the stick points directly south, it is solar noon.

You can see from this graph that you have a relatively limited "window of opportunity" to make your stress readings. As stress becomes more and more severe, this window becomes wider. Crop managers are usually interested in avoiding severe stress. When stress is first indicated during this mid-day period, the crop is basically non-stressed the rest of the day. By operating near this mid-day peak, you are using the Scheduler at its best.

Points to Remember

Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour.

Daily Index Patterns

The pattern of the index between sampling dates is VERY important.

The first thing you need to know is "what's normal for this crop?"

The second thing you need to know is "how does this field compare with "normal?"

YOU MUST UNDERSTAND THE BIG PICTURE IN ORDER TO UNDERSTAND INDEX READINGS. The index for every crop has a normal pattern. For example, a row crop, such as cotton, would have a seasonal pattern like the one on the next page. The dotted lines represent the upper and lower limits to normal readings. If an index value is above the upper line, the crop is under stress. If an index value is between the lines, it means the crop is not under stress.

Reasons the index can be above normal:

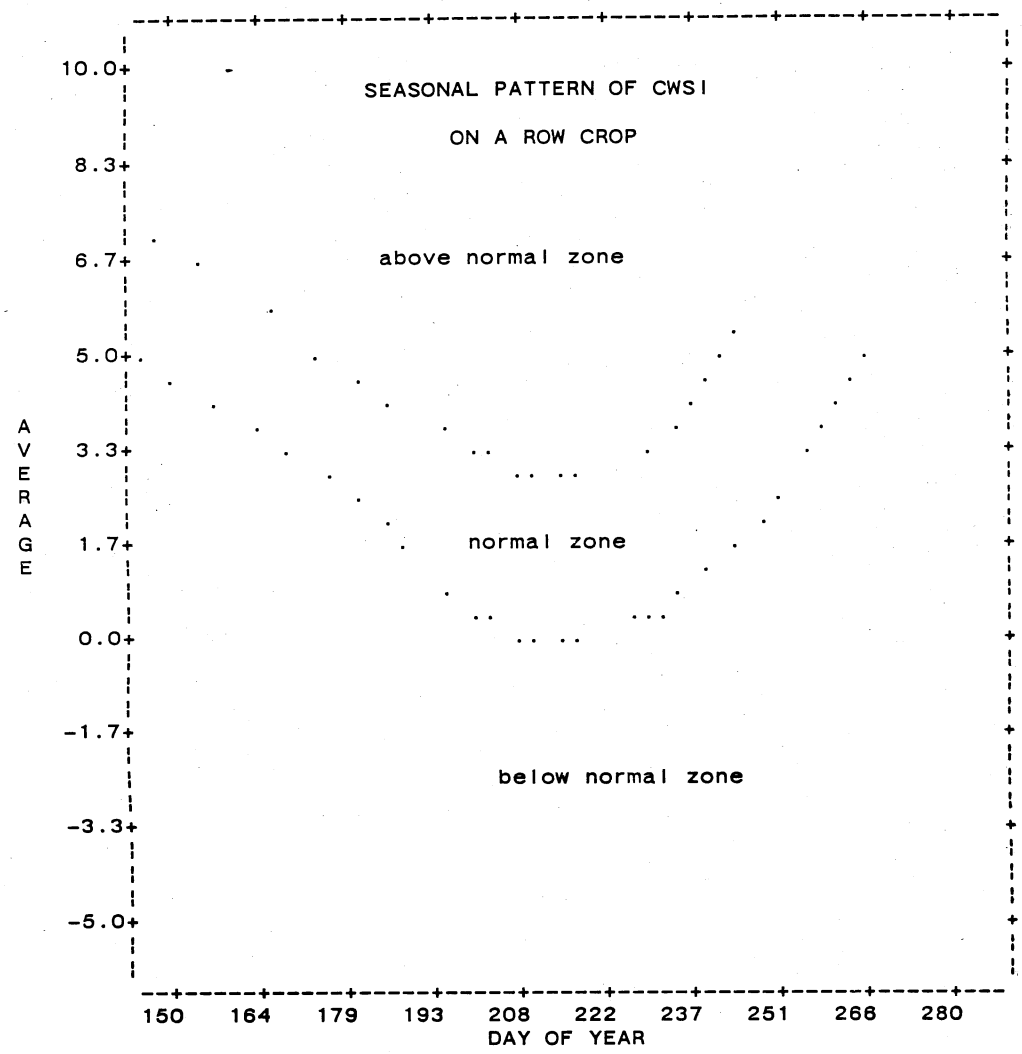
- Crop is under stress
- Sensor gun is too cold

Reasons the index can be below normal:

- Crop is wet
- Wrong time of day
- Poor aiming technique
- Unusually cool air
- Sensor gun was too hot

Points to Remember

You must know the BIG PICTURE for a crop to know what is normal.



Oops. There's a new term on the horizontal axis: "DAY OF YEAR". What's that? All we do is give every day in the year a number (there are 365 days in the year). So, January 1 is DAY 1, January 2 is DAY 2 etc. This table might help you understand:

Month	Days of Year
January	1-31
February	32-59
March	60-90
April	91-120
May	121-151
June	152-181
July	182-212
August	213-243
September	244-273
October	274-304
November	305-334
December	335-365

It's a little tougher to find a date on a graph using DAY OF YEAR values, but it's a whole lot easier to graph the information on a computer.

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The normal management objective on most crops is to either have the index decrease with time, or be stable with time. An index is "stable" with time, if it stays within a zone about 3 index units wide. For example, readings would be considered stable if they remained between -2 and 0 or if they remained between 1 and 3. Many users can maintain a zone of stability with smaller limits than these, especially users who have drip irrigation systems. When you are analyzing index patterns, the key is the trend (increasing, decreasing, or staying flat).

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1.4.7 Factors Which Affect Index Values

Anyone who is experienced with plants knows that many cultural practices affect plants. Anything that affects a plant has the potential to affect the index. Factors which are known to influence index values include:

- Variety. With some crops, such as corn, varietal differences appear to be small. Some crops, such as grapes, appear to have significant varietal differences caused primarily by leaf size differences. The spread in index readings may be up to 2 index units. This does not mean that you need a separate baseline for each variety. It does mean that a user will probably have to use the Scheduler for a season on a particular variety before he will know what to expect for normal index readings.

- Wind. Studies indicate that wind speed fluctuations can cause a variation in plant temperature of 2 to 4 degrees F. This means that CWSI can be expected to fluctuate up to about 2 stress units as the wind speed varies. The key to obtaining accurate index numbers is sampling technique. Remember, plant temperature (and CWSI) are both fluctuating around a fairly stable average. Effective sampling technique will produce a good estimate of that average.

- Time of day. Plant temperatures are controlled by the sun. The sun changes in brightness (and its heating power) throughout the day. The sun is usually brightest and hottest at "high noon", or when the sun is directly south. There is only a small difference in the brightness or heating power of the sun plus or minus 1 hour of solar noon. Because the maximum air temperature for the day usually occurs after solar noon, the best time to sample is about 1 hour after solar noon. More about solar noon in the next section.

- Clouds. Clouds protect plants from the sun. You feel cooler when you step from the sun into the shade. Plants are cooler when the sun is behind a cloud. The index value which is of most value to a grower is the index value obtained when the sun is shining brightly. The index value will always be lower when the sun is behind a cloud than it is when the sun is shining.

****
The Scheduler is not a voltmeter which provides exactly the same answer every time you turn it on. The basic reason for this is that an agricultural crop is dynamic. It responds to a constantly changing environment. The guidelines we provide will be useful to initially judge the meaning of Scheduler data, but some user adjustments are inevitable.
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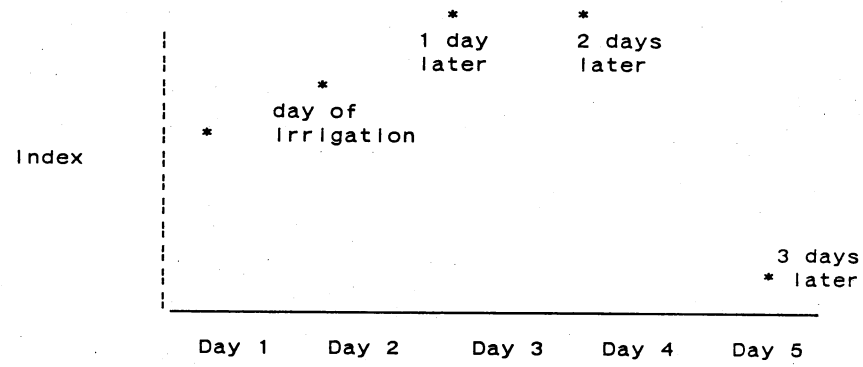
- Soil. Hot, dry soil will influence index readings. Remember, bare soil also has a temperature and an index value. Below are some index values for bare soil at various soil temperatures (assume air temperature is 90° F and relative humidity is 30%. The index values given are for cotton):

Soil Temperature	Index Reading
80	-1.0
90	6.1
100	13.3
110	20.5
120	27.6
130	34.8
140	42.0
150	49.2

You can see that soil temperatures may have no impact at all on index readings or the impact can be extremely strong. The hotter the soil temperature, the greater the impact. You must be careful to avoid soil in your readings.

- Too much water. Over-irrigation can affect the index (it affects plants also). The reason is simple: plants need water and air in the soil in order to function properly. It would not be unusual to see the following:



WHAT'S GOING ON? Isn't an irrigation suppose to make stress go away? In theory, yes, but in reality, some irrigations (for a few days) create stress. The reason is simple: heavy irrigations force the oxygen out of the soil. Without oxygen, plant roots are unable to use soil water. So, if you run out to the field the day after an irrigation, don't be suprised if you see the stress levels increase instead of decrease.

1.4.8 Relating the Index to Other Measurements

Yes, there is more than one way to measure plant stress. One request which we constantly hear goes something like this "Well, what is the relationship between the stress index and whatever it is that the customer is currently using?" The idea is that it would be very nice if we could make an index reading and tell the customer "This reading is equal to XXX soil moisture, or XXX tension, or XXX pressure potential, etc."

Yes, that would be very nice. But it's not going to happen. Think about it this way. Let's suppose we want to develop a relationship between these two things: a) the type of-house a person lives in and b) the income level a person has.

It takes no great stretch of the imagination to realize that these two things are strongly related. We could say, with a great deal of confidence, "In general, the more expensive the house a person lives in, the higher their income level". Right? This is just like saying "In general there is a relationship between the stress index and soil moisture, soil tension, and pressure potential.

In general. But now, an FBI agent comes to you and says "I want you to tell me the income level of Mr. X. Go take a look at his house, then return and tell me how much money he makes." Guess what! You couldn't do it. Despite the fact that you know "In general" the type of house a man lives in reflects his income, there is no way to predict this for a specific individual. There are simply too many other unknowns. For example, does his wife work or does he have a rich uncle, or is he deep in debt, etc.

This principle holds true for comparing stress index readings with other readings. There is, in general, a strong relationship between index readings and other measurements. But too many unknowns exist to develop general relationships. The index measures the stress level. Other techniques were designed to measure other things. If you want to know plant water potential, then measure it with a pressure chamber. If you want to know soil moisture, then measure it with a neutron probe. If you want to know the stress level, then measure it with a Scheduler.

1.5 INSTRUMENTS FOR MEASURING STRESS

1.5.1 Reasons for Needing Instruments

Growers have been producing crops for many years without using technical instruments to help them make decisions. So why should they start? After all, most growers know they can produce X tons per acre by making all their decisions "by the seat of the pants" or "experience." But, the truth is that plants have the potential to produce more than most growers achieve. A grower must have a desire to solve a problem before he will recognize the need to start using an instrument such as the Scheduler. Problems include:

- Large acreages. They have a need to obtain information rapidly about many different sections of their operation. The Scheduler was designed specifically to obtain information rapidly. Current grower techniques are often based on small samples of a few plants or localized soil samples.

- Manpower. They may have an insufficient number of trained people to help. They need inexpensive assistance in obtaining quality information about the current condition of their crop. When you look at the number of acres that one person can monitor with a Scheduler, the cost of the unit is very small on a per acre basis.

- Uniformity. Some sections of the farm may be in super condition, and other sections may have some real problems. Ultimately, this costs the grower money. Many problems are induced by the grower because growers do not have the information they need to discriminate differences in crop condition between areas until visual symptoms occur, at which point yields are often already damaged. The Scheduler allows a grower to manage sections so that stress levels remain as uniform as possible.

- Confidence in current techniques. Many of the current techniques growers are using are not very satisfactory. There is often a desire for something better. We believe the Scheduler is better than other devices growers use.

- Documentation. Growers like to see "the season at a glance." To do this with current techniques requires a great deal of effort in learning to understand computers, in developing software, and in entering data into a computer. The Scheduler provides a grower with two very useful forms of documentation.

1.5.2 The Plant is the Key

The ideal moisture stress reading is based on a direct plant measurement instead of a soil or atmospheric measurement (Clark, 1973). Think about this. Agriculture is concerned primarily with growing plants. Does it make sense to ignore information which comes directly from the plant? Of course not. It is important to understand that the plant is the best guide to its condition. Suppose you went to the doctor because you were feeling bad. Then, the doctor phones up the National Weather Bureau to find out the weather forecast. He then says, "Yup, I think you're probably going stay sick for about 3 or 4 more days." There's no doubt the weather is an important factor in making people sick, but wouldn't you feel just a little more confident in the doctor's diagnosis if he said "stick out your tongue and say AAAAH". Why do some growers feel they can ignore direct plant measurements and still achieve maximum productivity (and profit)? It doesn't make sense. The main reason farms exist is to produce plants and plant products. A manager has two choices:

- Measure the environment (soil, weather) and guess the condition of the plant.

- Directly measure plant condition as well as the environment.

Why make guesses about plant condition when it so easy to make direct measurements?

1.5.3 Instrument Requirements

PLANT TEMPERATURE IS THE KEY TO PLANT CONDITION.

Instruments designed to measure water stress should:

1. Measure canopy temperature accurately. Plant temperature is the key to understanding plant behavior. Everything that a plant does is controlled by the temperature of the plant. While we do not understand everything there is about plant temperatures, we do understand that plant Temperatues can be "below normal", "normal" and "above normal." It only makes sense that plant temperature measurements be as accurate as possible.

2. Be portable. this would allow measurements to be made anywhere that is desired. The instrument must not weigh too much or be too clumsy to use.

3. Be rugged and sturdy for use in the field. Any piece of equipment used in the field is exposed to jarring, bouncing, hot and cold temperatures, and dust (among other things). Many "laboratory quality" instruments would be destroyed by the way farmers would handle them. If it isn't rugged, don't use it in the field.

4. Allow for multiple readings in the field. The reason is simple : fields are variable. One section may have a heavy soil, another section may have salt problems. One sample of one plant is a poor representation of the overall average. It must be possible to sample many plants in order to have confidence that the reading represents the true average.

5. Be simple to use. No matter how good it is, if it isn't simple to use, most growers will not use it.

6. Correlate well with physiological measurements. Instrument readings must make sense. The instrument must be designed to provide information which relates directly to the condition of the plant. This means the scientific basis for the instrument must be strong. The Scheduler design fulfills these requirements.

1.5.4 Scheduler^{R} Hardware Features

- Aspirated air temperature and humidity sensors.
- Infrared thermometer

  Distance: one inch to infinity
  Range: $\pm$ 108^{o}F from ambient
  Field of view: 8^{o}
  Spectral response: 8-14 um
  Accuracy: $\pm$ 1.0^{o}F
  Repeatability: $\pm$ 0.4^{o}C
  Emissivity: 0.99
  Operating distance: 1 inch to infinity

- Ambient temperature

  Range: 32^{o}F to 140^{o}F
  Accuracy: $\pm$ 1.0^{o}F
  Resolution: 0.2^{o}F

- Humidity

  Range: 0 to 100%
  Accuracy: $\pm$ 5%

- Solar Radiation:

  Range: 0 to 100 mW/cm^{2}
  Accuracy: $\pm$ 10%

- Response Time:

  Screen update < 2.0 seconds
  Sample frequency < 0.5 seconds

- Microprocessor: 64-K -- 8 bit.
- Display: 2-1/2 X 1-1/2 LCD on processor

  1-1/2 X 1 inch on sensor gun

- Serial Interface:

  RS-232 25 pin male connection
  Baud Rates: 50-2400 (selectable)
  Character Sizes: 5-8 (selectable)
  Other download parameters also selectable

- Softside carry case.
- Warranty: 1 year
- Power -- 6 C cell batteries, with an expected life of 20 operating hours.
- Recharging port provided for use with rechargeable batteries.

CHAPTER 2 - SAMPLING TECHNIQUES

2.1 Guidelines

The major concerns in sampling are :

1. **Operating a clean unit.** Use in dusty conditions requires clean the cleaning of the lens of the infrared thermometer. When the lens becomes dirty, the temperature readings are lower than they should be. This results in index readings lower than they should be. The instruction manual will give you complete instructions.

2. **Adjusting to ambient conditions.** If the sensor gun is stored in a cold office, or a hot truck, the air temperature reading may not be accurate, even after the 94 second cound-down. Some common sense must be applied to allowing the gun to adjust to the outside. This is very important in the first 10-15 minutes of operation.

   One technique used to insure the gun has adjusted is to stand in one spot and take multiple samples. When you obtain index averages, from 3 separate samples, that are within 0.5 stress units, the gun is adjusted.

3. **Time of day.** The user should be consistent with time of day. He should return to measure the same field at about the same time each day.

4. **Proper aiming technique.** The steps to aiming properly are:

   a. Keep the sun at your back.

   b. Keep the gun 3 feet above the soil. When soil is hot and dry, it heats the air near the surface and affects the index readings.

   c. Select a target that avoids soil, sky, shadows, wood, or anything that is not green, sunlit vegetation.

      - Aim at individual leaves.

      - Aim down the row (refer to the chart on spot size to make sure you don't aim too far down the row, especially when bare soil is between the rows).

      - Make your own sampling surface if necessary. On small leafed crops, for example pecans, it may be necessary to "bunch" leaves to create a surface of sunlit leaves to sample.

   d. Aim at the crop at least 2 seconds before squeezing the trigger. This insures that you do not accidentally enter erroneous data.

   e. Do not aim more than about 30 feet from the point you are standing. Remember, when you aim at a target 30 feet away, you are really seeing a target that is about 4 feet wide and 270 feet long.

5. Sampling spot. One of the keys to interpreting the stress index readings is the trend of the index (is it increasing or decreasing with time?). This makes it important for a user to sample the same spot on different days.

6. Has the user selected spots which make sense in terms of his irrigation system? With an effective sampling scheme, there will be sufficient time to collect data on most farms.

7. How does the user treat the instrument between fields? After he samples one area, and is traveling to the next, what happens to the sensor gun? The "nose" of the gun should NOT be placed back in the holster. A good travel technique during a sample session is to place the gun upside down in the holster. The fan SHOULD remain on at all times. This is not the time to worry about battery life. Your concern at this point is accuracy. Air conditioning (for 5-10 minutes) should not affect the accuracy of the sensor head.

8. How much abuse is the sensor gun, especially the coiled cord, receiving? Cord failures can occur in units in which the cord is twisted, knotted and yanked on. Symptoms of a broken cord are:

   - Software locks up (caution, the software can lock up in the R&D models if one of the computer parameters is accidentlly changed. Check to make sure XON/XOFF is DISABLED.

   - Sensor readings become wild (canopy temperature of 300 degrees or relative humidity of -1000% , etc.)

9. Do not take an excessive number of data points in one spot. In spite of its great number collecting ability, all you need is about 10-15 shots per location.

10. Stable sunlight. The sunlight sensor on the

Scheduler is designed for relative readings. The highest reading you obtain on one unit may be an 85 while a different unit may read 95. The reason for the measurement is to allow a user to decide:

- Was the reading near maximum (it should be), indicating a clear day and sufficiently strong sunlight?

- Were the readings stable? When you examine a print-out, the solar readings should be within about 10-15 units of each other. If the spread is greater than this, it may indicate the data was taken under partly cloudy skies, too early or late in the day, or the user was simply casting shade on the back of the gun with his body. You should ignore the solar readings when:

- You are sampling trees, the solar sensor was designed assuming the "nose" of the gun was pointed slightly down.

- Winter-time. The Scheduler is not used by many during the winter months. The sunlight sensor is inconsistent when the sun is at winter-time elevations. The other sensors are not affected.

2.2 Time of day

If you have 1 hours worth of data to take, the best time to start would be 90 minutes after solar noon. Try to arrange the customers sampling so that all samples can be taken in 1 hour. It's surprising how much acreage can be sampled in an hour once the irrigation scheme on a farm is understood.

If you have 2 hours worth of data to take, then start 30 minutes after solar noon. The index may change some during this time, but should not be a serious concern.

If you have 3 hours worth of data to take, then start 30 minutes before solar noon. There may be a noticeable change in the index between the first and last samples, depending on how much the air temperature changes.

If a user absolutely feels that he cannot make readings between solar noon and the two hours afterward, then he must be reminded to :

- Be consistent. Always sample the same area at the same time of day.

- Do not compare index values taken at 11:00 with index values taken at 2:00. They will probably be different. Refer to figure 1 to see the normal daily index pattern.

In some areas, clouds may develop in the afternoon. This means that the environment becomes more moderate. The best time to start sampling in such areas is about 1 hour before clouds usually start developing.

CHAPTER 3 - DATA ANALYSIS

3.1 What Is Data Analysis?

In the most unscientific sence, it is the scheme for evaluating the results of field sampling.

3.2 Data Quality Control

Is the crop temperature data acceptable?

One key to deciding if crop temperature data is acceptable is to examing the STD, or standard deviation value. STD is a measure of how uniform the canopy temperature samples were. Some variability is expected, and some can be caused by stress, but STD should be within normal limits (2-4^{o} F). We have found that even researchers who have 2-3 years experience with the Scheduler periodically store samples which have STD values which are unacceptable.

It is more difficult to answer this question in the PRODUCTION models, since there is no room in the software for calculating STD. One indication of improper sampling will be a canopy temperature average that is very different from the others. You must be careful about using differences in averages, however, since this is exactly what you are looking for.

Is the air temperature data acceptable?

This can be decided by looking at a graph of air temperature versus time. If the user has a clear pattern in his air temperature data (increasing or decreasing with time) it probably indicates the sensor gun was either too hot or too cool. Patterns in the air temprature data can invalidate part or all of a data set.

Were effective sampling techniques used?

This is a judgment call. Chapter 2 should be studied and thoroughly understood. If you are confident in the sampling, and the data do not indicate a problem, then proceed.

3.3 Key Facts to Remember

The following facts apply to the leaves of most crops. Keep these facts in mind as you respond to individual questions from growers.

- Young leaves are cooler than old leaves in some crops and warmer than old leaves in other crops.
- Individual leaf temperatures constantly fluctuate around an average value.
- Leaves can wilt when stressed or non-stressed. Plants that are wilted, but have adequate soil moisture, will be cooler than wilted plants that are moisture stressed.
- Stressed leaves can be up to 20^{o} F hotter than non-stressed leaves.
- Non-stressed leaves are generally cooler than ambient in most crops.
- Stressed leaves are generally above air temperature.
- Measureable increases in leaf temperature occur 1 or more days before visible wilting occurs.
- Differences in temperature between stressed and non-stressed plants are directly correlated with differences in their transpiration rates.
- Plants growing in saline soil may be much hotter than plants growing in non-saline soil.
- Leaf temperatures of different varieties may differ by 2-4 F under the same soil moisture conditions.
- Differences in yields are associated with differences in leaf temperatures.

CHAPTER 4 - DOWNLOADING TO A P.C.

If there's one problem you don't need when you're showing the Scheduler to a grower, its trouble with his p.c. You haven't got the time, nor the interest, in becoming a computer expert (but the grower will think you should be one). So what should you do?

As it turns out, it's relatively easy to solve most of the problems you will encounter. Let's take them 1 by 1.

4.1 Testing the Grower's P.C.

Problem #1. Does the customer's computer have the necessary hardware? The necessary hardware is called an RS-232 port. Have you ever looked on the back of a computer. There can be all sorts of things back there. And none of them marked. So now what? Simple. Do this:

1. Turn the computer on.

2. If a C> appears on the screen, then type "A>" (without quote marks) and press the ENTER or RETURN key.

3. Now that you have an A>, place the Scheduler support analysis disk into the A drive.

4. Next, type the word "MENU" (without quotes) and press the ENTER or RETURN key.

The program will present you with its main menu. Press "U" to select utilities

The utilities menu has two options :

1. Test the growers's computer.
2. Import test file.

Select option 1. The program will automatically test the computer. You will see a screen that looks like this:

Status According to RAM

Total Memory	640 Kbytes	Disk Drives	2
I/O Memory	2 Kbytes	Parallel Ports	1
Sys-Brd Mem	64 Kbytes	Serial Ports	2
Video def	80 X 25 color card	Game adapter	YES

The ansers will be different for every computer.

If the grower's computer has the necessary hardware, you will then see this sentence:
"According to RAM, you have 1 (or 2) RS-232 ports"

The program will automatically take you to the next step.

If the grower's computer does not have the necessary hardware, you will see this sentence:

"According to RAM, you cannot down-load a Scheduler to this P.C. An RS-232 card must be installed".

The program will then return to the main menu.

Problem #2. Now that you know the grower has 1 or 2 RS-232 ports, how do you find it? There are two rules:

1. The port has either 9 pins or 25 pins.

2. The port has male pins. Computers also have 25 pin female plugs which are used to connect the computer to a printer. A 25 pin female connector will not usually work. (Radio Shack is one brand which uses female RS-232 plugs).

You'll have to find these yourself. Just follow the two rules above. If neither of these tests work, give us a call.

Problem #3. The computer has a 9 pin male RS-232 port, but the Scheduler comes with a 25 pin male plug. All you do is put an adapter between the Scheduler plug and the computer. You should always carry two types of adapters with you:

1. 25 pin female-female adapter.
2. 9 pin to 25 pin female-female adapter.

By this time, you should have been able to learn that the computer should work and make the necessary physical connections.

Problem #4. Is the COM port the Scheduler is hooked up to called COM 1 or COM 2? Who cares anyway? Well, it's an unfortunate computer fact, but you have to learn the answer to this question. The TEST program makes this easy, too.

At this point, the program will take you step by step through the COM port identification procedure. All you'll need to do is answer a few questions which the program will ask and also insert a special RS-232 tester between the Scheduler and the computer (these are available from many sources for between $ 7 and $15 each).

At this point, you will be ready to down-load a Scheduler into the computer. The program will automatically return you to the main menu.

1989

Trouble Shooting Croplink^{tm}

First : Familiarize yourself with figures 1 and 2. Fig 1 shows the location of the three circuit boards used in field stations. Figure 2 shows the voltages and connections that are appropriate for each circuit board. Figures 1 and 2 can be used to isolate problems which may develop.

Most problems with Croplink^{tm} stations are battery related.

Second:
Is the battery sufficiently charged ? The battery voltage should be about 12.0 volts. In no case should the battery voltage be less than 11.0 volts. Sensor accuracy and communications problems can occur with lower voltages. Check the battery voltage by attaching the negative lead of a voltmeter to pin 11 of PCB 1 and the positive lead to pin 10 of PCB1 (see figure 2). If the battery voltage is improper, then check all battery and solar panel connections. You should also measure 12 volts on pin 18 of PCB 1.

Third:
If the battery voltage is o.k., then physically check the bottom of PCB 1 to see if any of the "traces" (the funny looking lines) has melted. If the battery polarity has been accidentally reversed, some of these traces could melt, thus creating open circuits. These circuits can be repaired by soldering a wire across the melted spot.

Fourth:
Check the bottom of PCB 2 to see if any of the traces have melted. If not, then leave the negative lead of the voltmeter on pin 11 of PCB 1 and put the positive lead on any negative numbered pin (1,3,5,7, etc.) of PCB 2. You should measure 12 volts. If you don't, there is a problem with the connection between PCB 1 and PCB2.

Fifth :
Check the bottom of PCB 3 for open traces. Leave the negative lead of your voltmeter on pin 11 of PCB 1 and attach the positive lead to pin 25 of PCB 3. Then press the test switch on PCB 2. If you do not measure + 5.0 volts on pin 27 when the switch is depressed, there is a problem in one of the components. The field station circuit boards will need to be retured to the factory for repair.

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

CROPLINK FIELD STATION

Location of PCB Boards

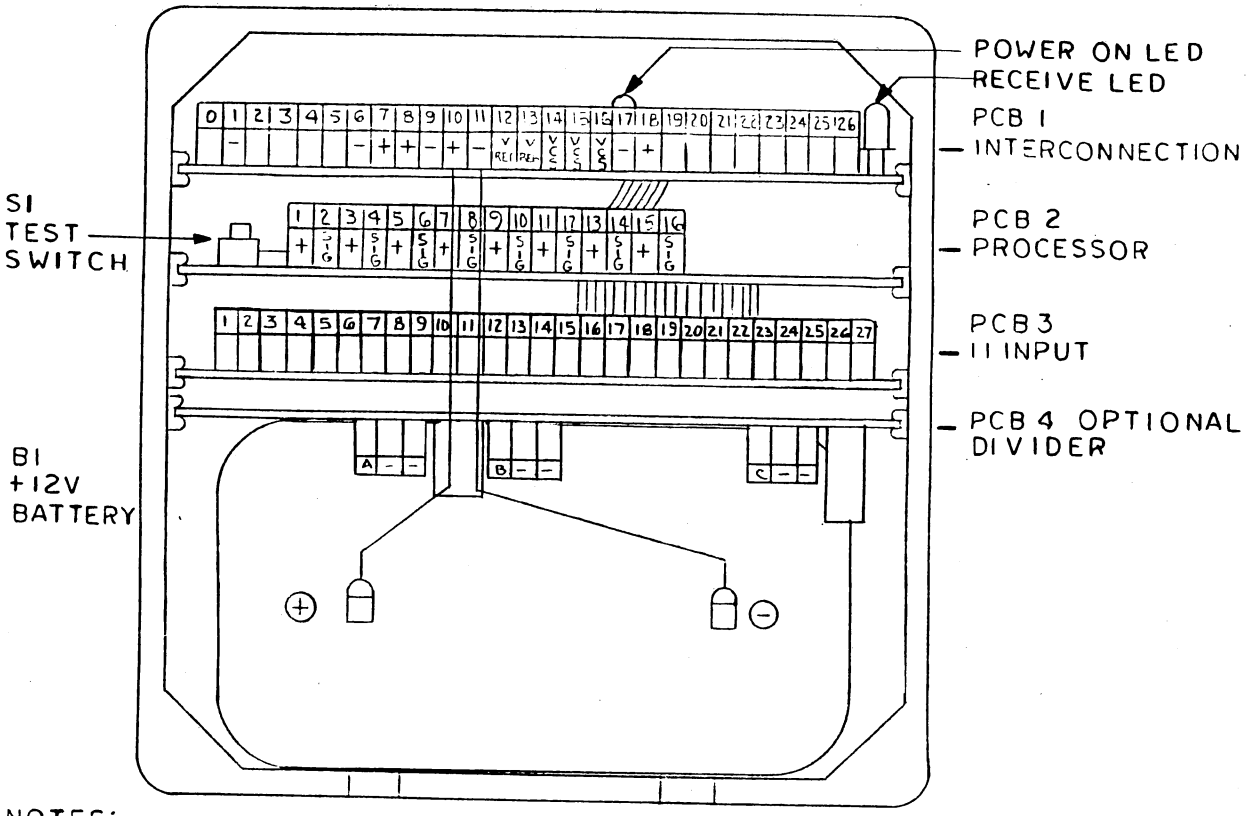


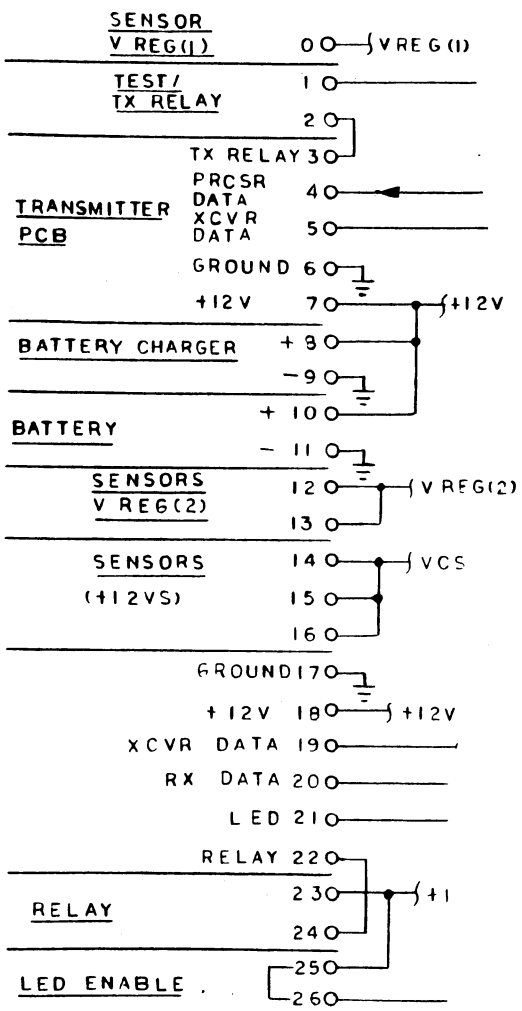
Figure 1

NOTES:
1. FOR SENSOR AND CONTROL CONNECTION SEE WIRE INSTALLATION TABLE

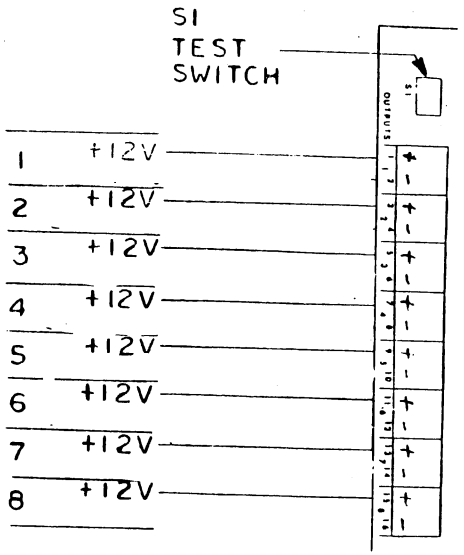
TOLERANCES UNLESS OTHERWISE SPECIFIED FRACTIONS ± DEC ± ANGLES ±		ANALOG/DIGITAL FIELD STATION CHASSIS ASSEMBLY DWG	
APPROVALS	DATE		
DRAWN m	5-3-85		
CHECKED		SCALE FULL	SIZE B / DRAWING NO. 1R68 0SB01
		DO NOT SCALE DRAWING	SHEET

BISHOP GRAPHICS INC
REORDER NO. 20521

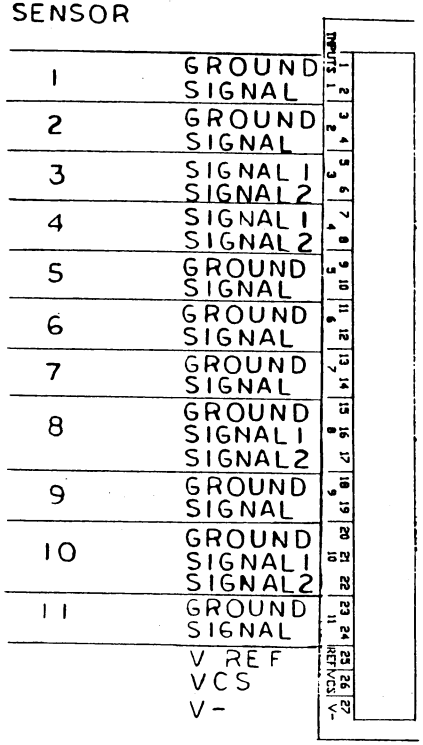
PCB 1



PCB 2



PCB 3



Wiring connections for Croplink PCB boards.

Figure 2

COMMON QUESTIONS GROWERS ASK ABOUT THE SCHEDULER

Is the Scheduler™ too scientific to learn to use and will it require training?

Ten to fifteen minutes of in-field training has always proven sufficient to make a new owner comfortable. The Scheduler's non-eraseable software program is written with the grower in mind. It will remind you if you've done something wrong and the software's "help" function will guide you to successful use. A twelve minute VHS training tape and operations manual are available.

I need to know when to water my crops before they are water stressed. Can the Scheduler tell me this?

Plants have the amazing ability to produce top yields when soil moisture is less than 100 percent of field capacity. For many crops Scheduler picks up reductions in plant transpiration, days before the crop experiences visible stress. **Scheduler can tell you when your plants are well watered as well as stressed.**

I have always scheduled irrigation by measuring soil moisture. How does the Scheduler compare?

Managing soil moisture to maintain a "healthy plant" is what irrigation scheduling is all about. Measuring soil moisture can supply valuable information on water depth in the soil profile. Scheduler used in conjunction with your current system greatly improves the quality of your soil moisture information by providing direct "feed-back" from the plant. The Stress Index calculated by the Scheduler depends upon the plant's ability to extract moisture from the "root profile" which is usually an unknown when derived strictly from soil moisture information.

How is the system powered and do I need computer skills to operate it?

The system operates on six size C batteries with expected battery life of 20 hours of continuous operation. Of course, normal daily use is not a continuous effort, under these conditions one set of batteries will last about one month (rechargeable batteries available). No computer skills are required.

How many crops will one Scheduler analyze?

Each unit can hold crop specific models for up to five crops. Current crop models include corn, wheat, barley, potato, tomato, cotton, soybeans, sugar beets, cucumbers, grapes, alfalfa, grain sorghum, and several types of turf grass. You can select the five crops that best fit your operation.

Since it detects plant stress, will it tell me if I have other cropping problems?

The Scheduler will react to any problem that reduces the plant's transpiration rate. This reduction is usually caused by the lack of available soil moisture, but if soil moisture can be eliminated as a possible cause, many disease or insect problems can be identified. They usually appear as "hot spots" and spread throughout the field where Scheduler can aid in early detection of these troubled areas.

What if I want to use the Scheduler on a crop not listed?

We have developed two "all-purpose" indexes. They are labeled as having high and low sensitivities. This means that the scale changes (on a relative basis) either a small amount (low sensitivity) or a large amount (high sensitivity) for each one degree Fahrenheit change in crop temperature. **It is up to the user to select which index is best.**

Are there non-plant uses for the Scheduler?

Definitely. The number of applications depend on your type of operation and imagination. The Scheduler can be used to measure surface temperature of walls, animals, floors, grain, as well as air temperature and humidity. If you have a use for surface temperature or environmental information, the Scheduler can measure it for you.

Can I use the Scheduler on young row crops where a lot of soil is exposed?

The measurement technique is different than for a crop where the soil is covered by the plant canopy. For young plants, it is necessary to sample individual plants, since the amount of exposed soil is large. The Scheduler samples at a rate of once every 1/4 second. In just seconds, a user can sample more area than would ever be practical with tensiometers or moisture blocks. Remember, small plants do not have the root capacity or leaf area of larger plants and they are often surrounded by hot soil. Their "normal" state is to be slightly stressed.

Is wind speed important?

Yes. Fluctuations in wind speed cause fluctuations in plant temperature. The need to measure wind speed is minimized since the Scheduler directly measures plant temperatures and can collect a large number of samples to "average out" fluctuations.

Is the direction of the sun important?

It is important that the Scheduler sample only sunlit vegetation. Since many crops have a row structure (or shaded side) by keeping the sun at his back, a user can insure that he is looking at the sunny side of the row instead of the shaded side.

Are clouds important?

Yes. The Scheduler will not calculate the plant stress index if the sunlight level is not high enough. This is because plant stress is maximized under sunny conditions and minimized under cloudy conditions. The Scheduler will tell you when the light level is too low.

How important is time of day?

Very important. To measure plant stress it is necessary to do it when the stress appears, which is generally "in the heat of the day." It is important to be consistent in the time of day when the Scheduler is used. We prefer a time frame of around noon to 4:00 p.m. In many locations, the Scheduler can be used effectively as early as 11:00 a.m.

CWSI

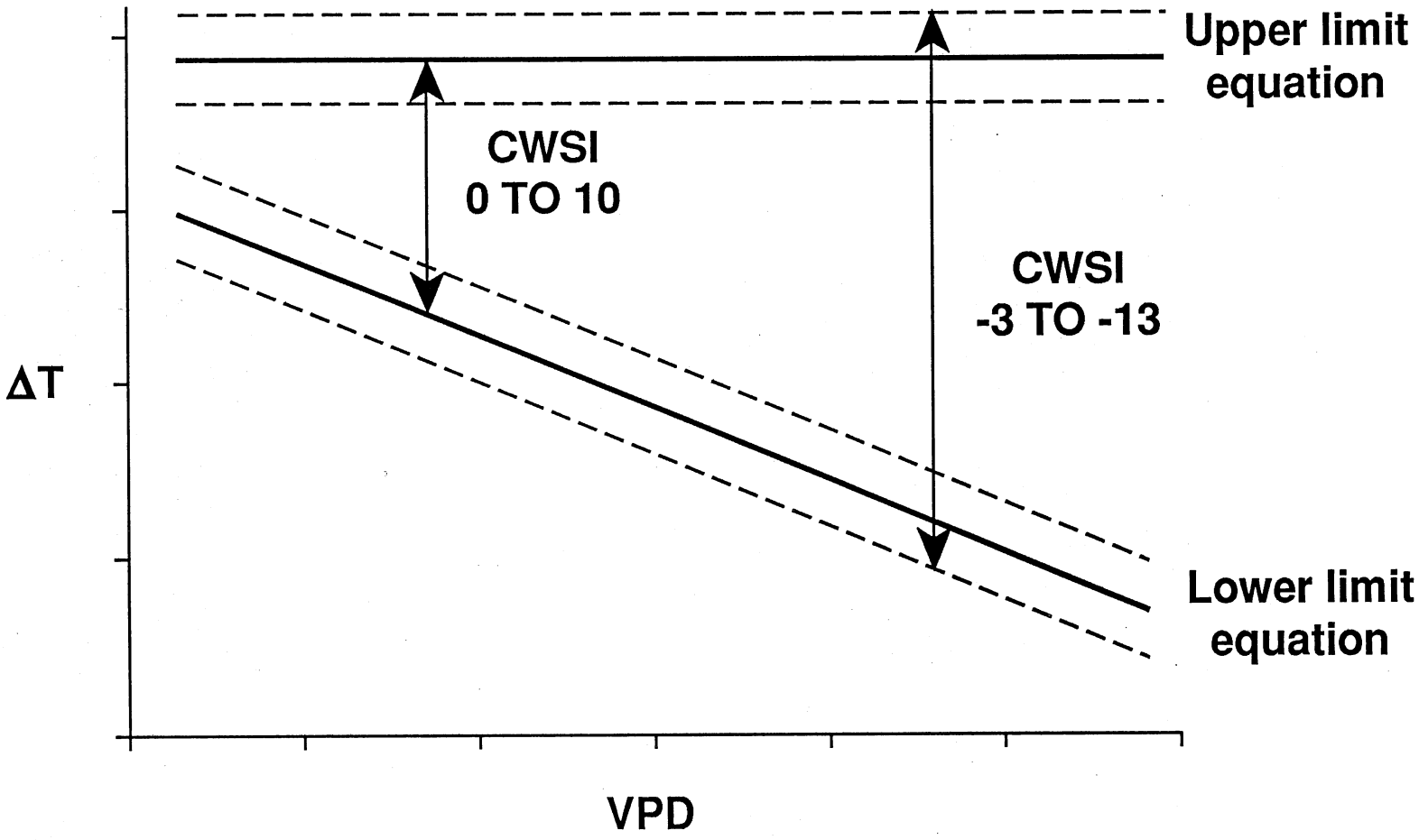
SIMPLE THEORY--COMPLEX REALITY

B.R. Gardner The Carborundum Co.

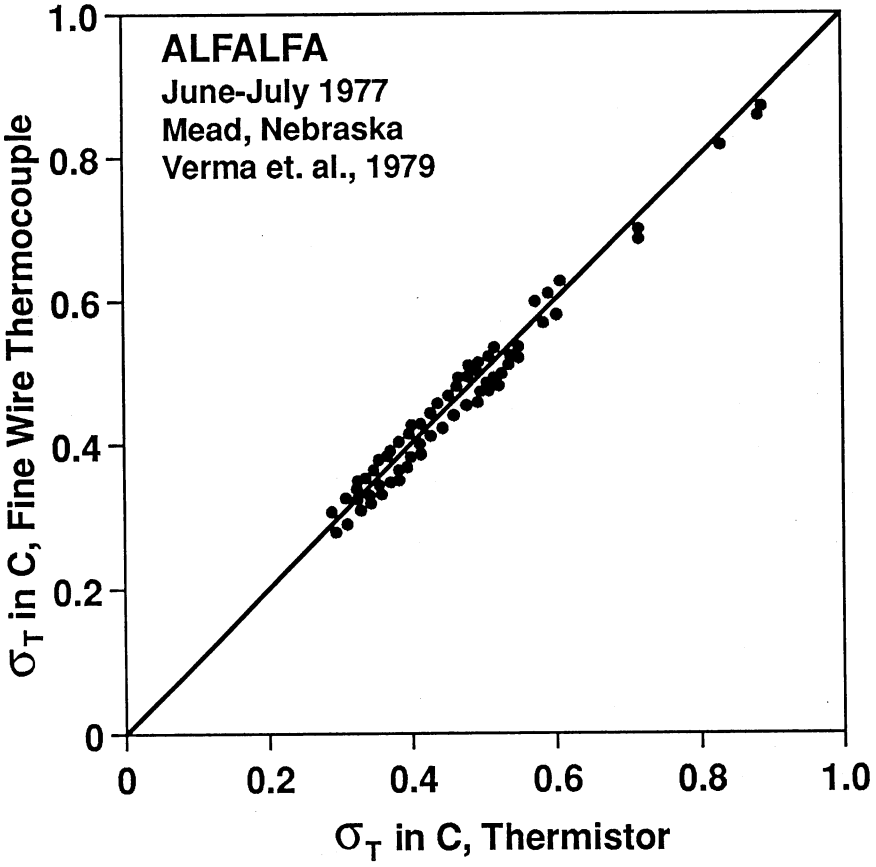
C.C. Shock Oregon State University

T.D. Stieber Oregon State University

THE PRACTICAL CWSI SCALE



AIR TEMPERATURE VARIABILITY
45 Minute Periods



1. σmax = 0.9 C
2. Range $T_A \approx$ 3.6 - 5.4 C
3. CWSI will vary greatly
4. Averaging is essential

CWSI AND CROP PHYSIOLOGY

$$LWP = (r_c + r_a)(R_N + G) - \frac{\rho c_p (r_c + r_a)(T_c - T_a)}{r_a} + \frac{R_g T_A \ln(RH)}{V_w}$$

(Gardner, 1987)

Theoretical relationships between crop physiology and crop temperature are needed.

WHY STATISTICAL TESTS FOR BASELINE DIFFERENCES MUST BE USED:

Eg. TURF

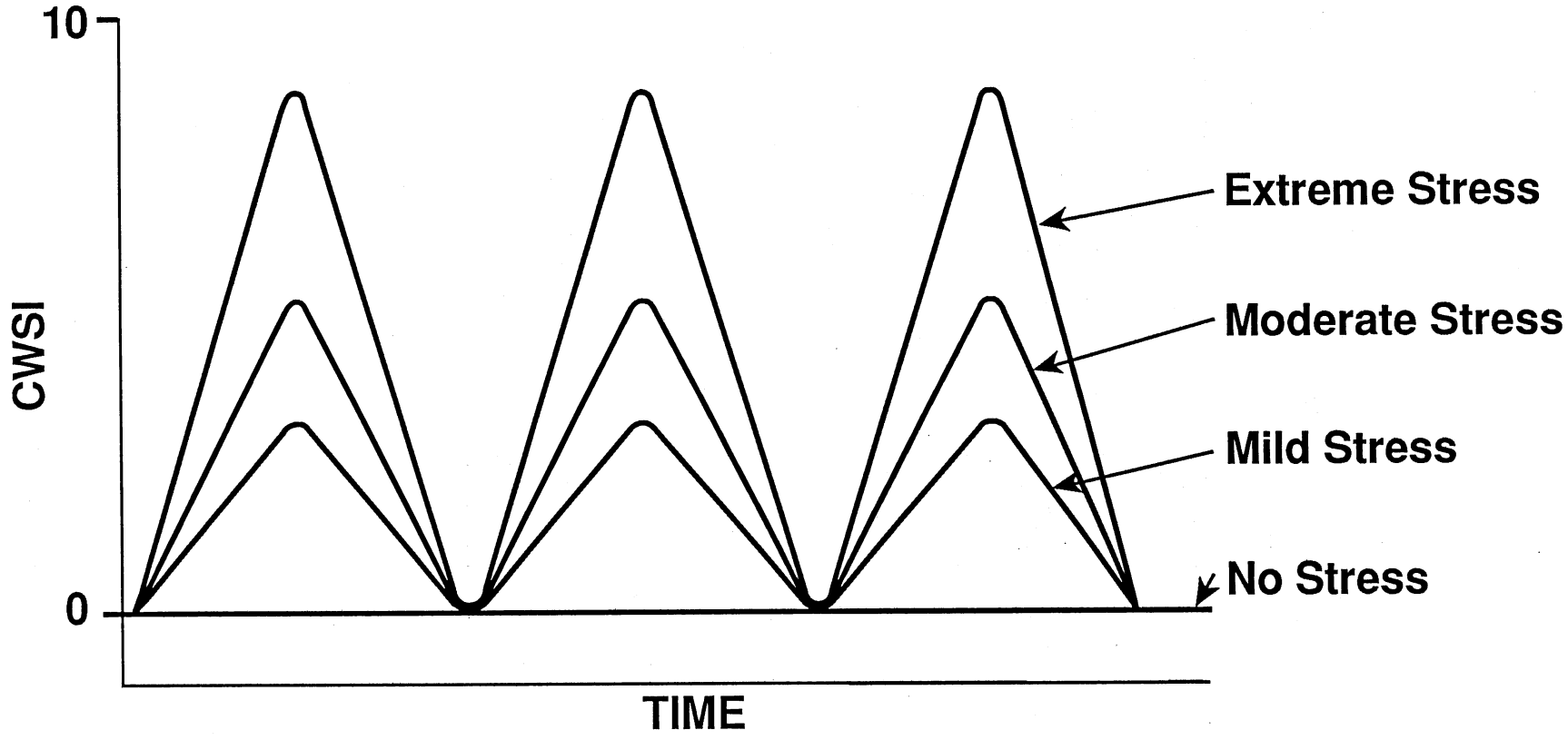
Baseline No. 1 $\Delta T = 8.3 - 2.3VPD$ Throssell, 1988

Baseline No. 2 $\Delta T = 4.7 - 0.86VPD$ Carrow, 1988

WELL WATERED TURF CROP, ΔT

	VPD VALUE					
BASELINE	0	1	2	3	4	5
No. 1	8.3	6.0	3.7	1.4	-0.9	-3.2
No. 2	4.7	3.8	3.0	2.1	1.3	0.4
Difference	3.6	2.2	0.7	-0.7	-2.2	-3.6
	No Data		Similar results in data range		No Data	

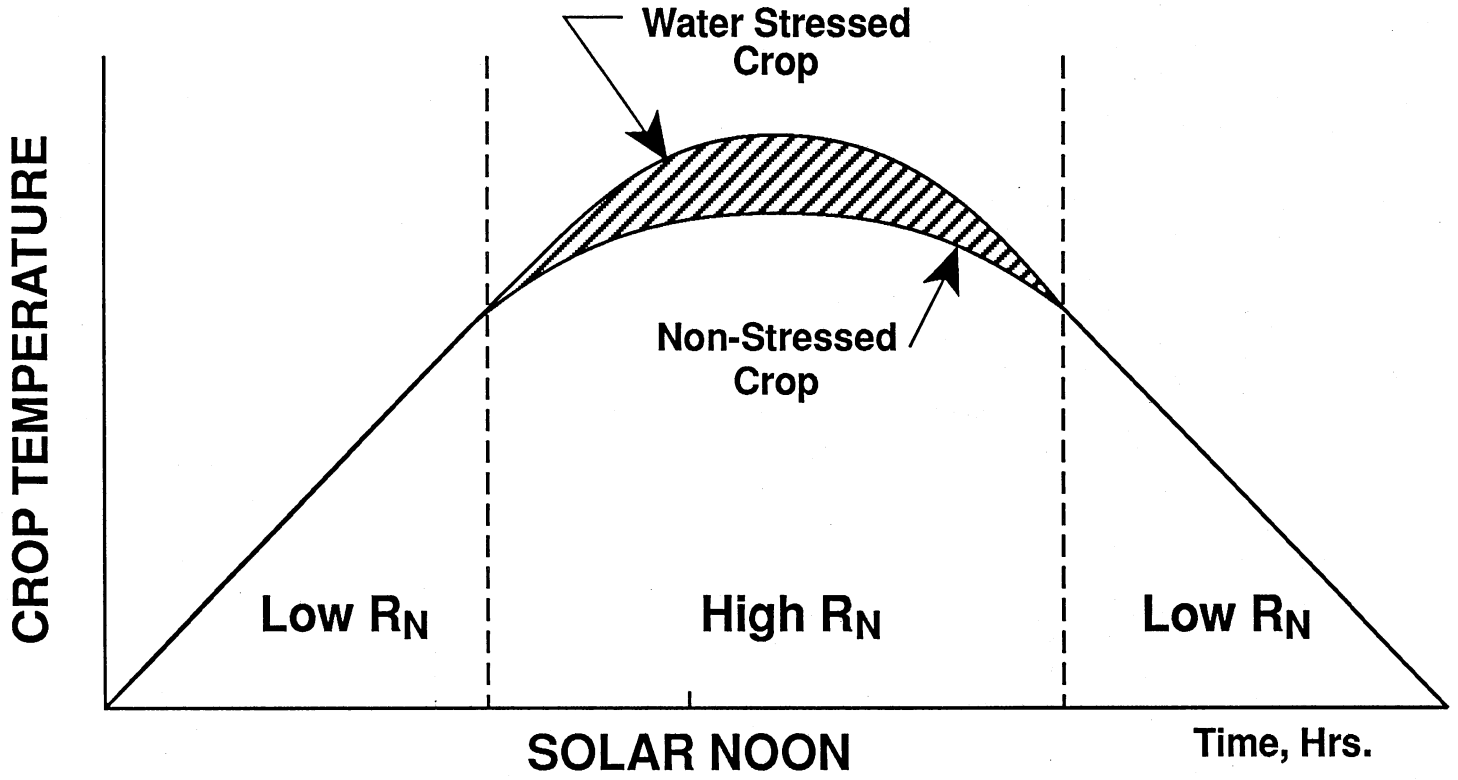
IDEAL CWSI CURVES



STRESS PATTERNS FOR VARIOUS CROPS

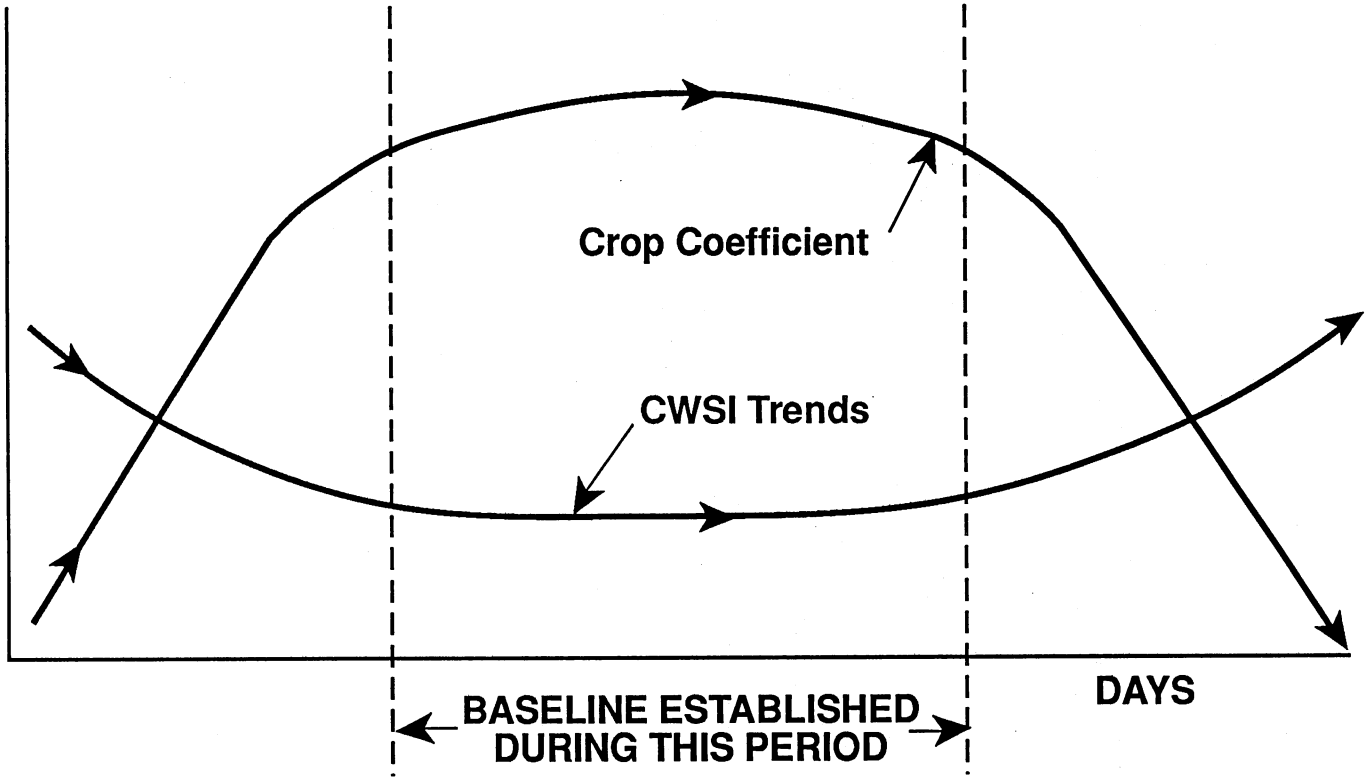
No stress : Potatoes
Mild Stress : Cotton
Moderate Stress : Sugar Beets
Extreme Stress : Seed Alfalfa

BASELINE DATA COLLECTION



CWSI NOT USEFUL	CWSI IS USEFUL	CWSI NOT USEFUL
R_N IS TOO LOW	R_N MUST BE HIGH	R_N IS TOO LOW
	CALIBRATION DATA	

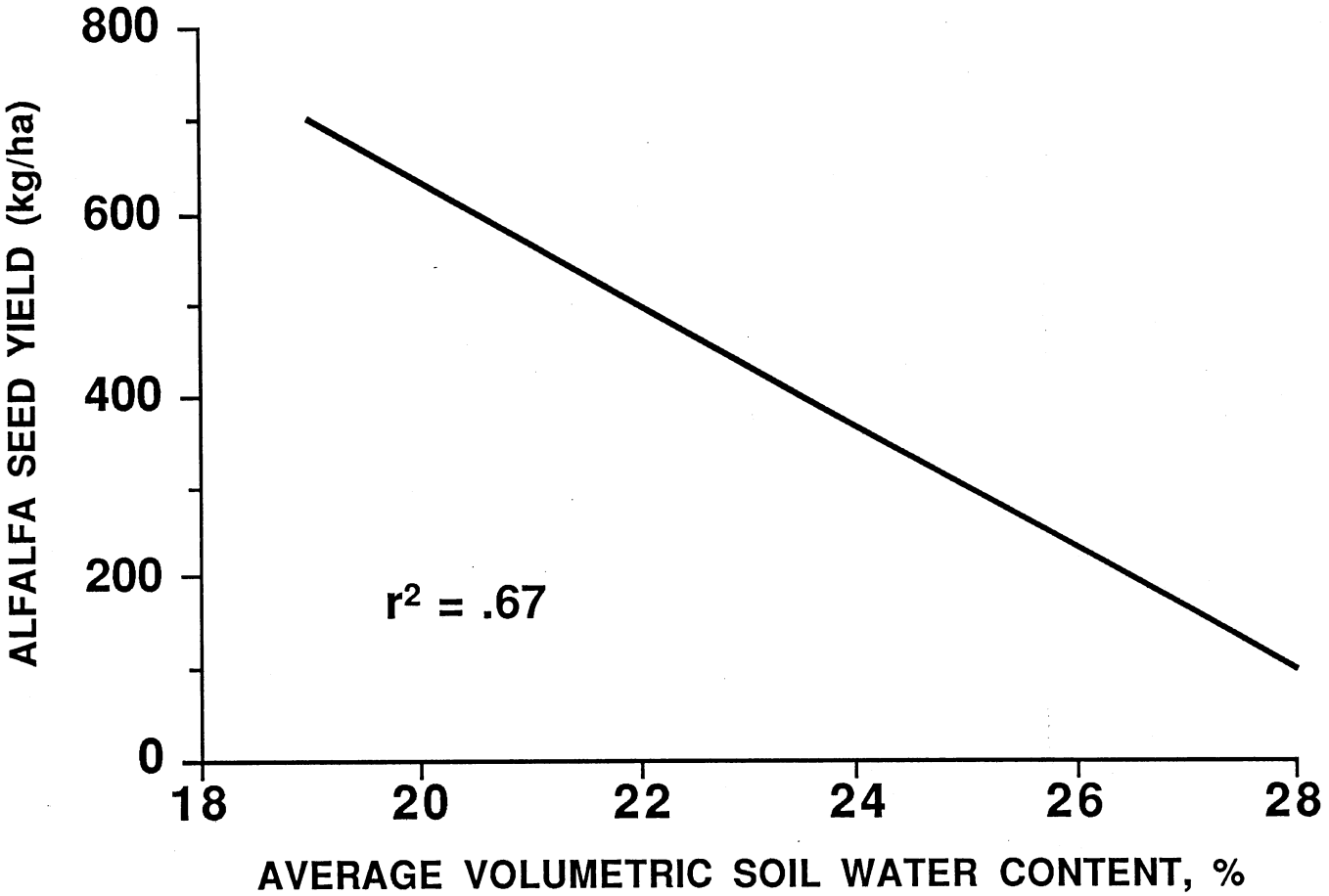
SEASONAL PATTERNS



Minimum CWSI = f(1- (Crop coefficient))
If mid-season baseline is used throughout the season.

RELATIONSHIP BETWEEN THE AVERAGE SOIL WATER CONTENT (30 to 60 cm) AND WRANGLER ALFALFA SEED YIELDS THE SOIL WATER WAS AVERAGED FROM BLOOM TO SEED FILL

Malheur Experiment Station, OSU, Ontario, Oregon, 1988.



Down Loading Instructions

for the ST27™ Turf Monitor

Using PC-Talk

A. Prepare the ST27 to send data

1. Configure the ST27 as follows :

Baud :	1200
Char. Size	7
Stop Bits	1
Parity	Even
Xon/Xoff	ENABLE

2. Connect the ST27 to the communications port of your computer. It may be necessary to use an adapter to do this, depending on whether you have a male or female adapter, a 9 pin connect or a 25 pin connector and whether or not you need a null modem (most people don't).

3. Turn the ST27 off then on.

4. Press PRINT twice. The ST27 is now prepared to send its data.

B. Prepare Your PC to receive data.

1. Copy the programs on the PC-TALK disk to your C: drive, or put the PC-TALK disk in your A:drive.

2. type "PC-TALK" and wait a few seconds while the program begins executing. A title page will appear

3. hit any key to continue the program

4. type "ALT-R" to open a new file. A set of parallel lines should appear.

5. name the new file. The format is drive: *.*
   where *.* is the DOS file name.
   example 1 : a:test.dat
   example 2 : c:test.dat
the data will be stored wherever you tell DOS to put it. Your pc is now ready to receive the ST27 data.

6. press "PRINT" on the ST27. The data should now dump.

7. type "ALT-R" to close the file.

8. type "ALT-X" to return to DOS.

9. type "PRINT" drive:*.* to produce a hard copy of your data file.

A sample data file called "TEST.DAT" is included on the disk.

Should it be necessary to change the communications parameters of PC-TALK type "HOME" to see your list of available options. The current settings of PC-TALK are :

ALT-P (communications default)

1200,E,7,1

ALT-F (program defaults)

Baud	1200	Screendump file	B:SCRNDUMP.PCT
Parity	Even	Redial delay	20
Data Bits	7	Connect Promt	Connect
Stops Bits	1	Line 25 Help	Y
Echo	N	Foreground	7
Messages	N	Background	0
Strip #1	0	High Inten.	15
Replace #1	0	Print Port.	LPT1:
Strip #2	0	Print Width	80
Replace #2	0	Comm. Init.	,CS,DS
Stripe #3	0	Modem Init.	''
Replace #3	0	C/R Subst.	}
Logged Drive	A:		
Margin Width	70		

HOW TO AVOID OVER-IRRIGATION
USING THE SCHEDULER^{R} PLANT STRESS MONITOR

By its very nature, over-irrigation is more difficult to detect than under-irrigation. Plants that are severely over-watered, especially in heavy soils, will suffer from a lack of oxygen to the roots. When this happens, the stress index will rise. High stress readings when the soil is saturated probably indicate an oxygen deficiency.

In many cases, the soil is not so over-watered that oxygen deficiency occurs. The excess water simply drains through the soil, carrying with it essential nutrients. There are no direct physiological symptoms which indicate excess water is being leached. Over-irrigation can be inferred from Scheduler^{R} readings, however.

If you suspect that a field is being over-irrigated, it will be necessary to monitor that field between irrigation cycles. If the stress readings remain essentially constant, or actually decrease between two irrigation events, then it is probable that irrigation was initiated too soon. The stress index should increase by 1-2 units above the value it had after an irrigation.

With flood irrigations, the soil is often temporarily saturated, causing oxygen deficiency symptoms. This makes it necessary to use as a reference, the stress readings obtained about 3 days after a flood irrigation.

Using this procedure, it is not necessary to place a strict interpretation on stress index values. It is important to use the Scheduler^{R} consistently when comparing trends. For example, do not compare stress readings obtained from single-leaf measurements with large-scale field readings. Early in the season, readings must be taken on individual plants. As a crop matures, the method used of aiming the Scheduler^{R} changes. Changing the aiming technique may change observed index values. This is not a serious problem, since the key to interpreting this index is "how much has it changed since the last irrigation?".

A change of 2 stress units is usually sufficient to initiate an irrigation. This ensures that the soil has dried sufficiently to allow oxygen to diffuse to the roots, without decreasing transpiration rates to the point where unwanted stress occurs.

HOW TO USE SCHEDULER^{R} STRESS INDEX READINGS

There are two ways of using Scheduler^{R} Plant Stress Monitor stress index readings:

1. Real-time. In this mode, the current value of the index is the sole criteria for determining whether a plant should be irrigated or is under stress. In order for this mode to be effective, it is necessary for the Scheduler^{R} to be used during mid-day, when the sun is shining brightly. This mode works best under hot conditions (air temperatures greater than 75^{o}F), but can be used effectively at cooler temperatures.

2. Cumulative. In this mode, it is necessary to measure index values on a daily basis, regardless of cloud cover. The index is summed, like growing degree days. This is the best mode of operating the Scheduler^{R} in cool and/or cloudy areas. Whenever the cumulative index reaches a pre-determined value (for a given soil type) irrigation is initiated to replace the volume of water used. The mid-day readings obtained should be representative of the general mid-day conditions. The index summation is reset after an irrigation or heavy rain. Since the index can be less than zero, some users prefer to sum only positive index readings.

OVERVIEW OF THE R & D SOFTWARE FOR THE SCHEDULER TM PLANT STRESS MONITOR

I. Turn the unit on. There are three options: HELP, PRINT, ENTER.

HELP - Provides a description of EACH key function.

PRINT - Selects the option to Print data, reconfigure the RS-232 parameters, or reset optional program features.

ENTER - Begin execution of the Main Program.

II. Key Descriptions

ENTER - Runs program, enter selected values of field, crop, date, or time.

PRINT - Selects the option to print data, reconfigure the RS-232 parameters, or reset optional program features.

UP AND DOWN ARROWS - Selects a value of field crop, date or time, or scroll to next screen when indicated.

CALC - The first push of CALC produces sample averages, after at least 1 data point is taken. The second push of CALC (after averages are computed) automatically increments the field number by 1 and re-starts the data collection screen. If CALC is pressed immediately after the machine is turned on, the battery voltage level will be shown.

HELP - Help is used to provide information at various points in the program.

III. Print Option

The Print option can only be accessed immediately after the machine is turned on. The Print options are: CALC, ENTER, PRINT.

A. CALC - Configurations Menu. Use the Up and Down Arrow keys and the ENTER key to select:

Baud Rate (50, 75, 150, 300, 600, 1200, 1800, or 2400)
Char Size (5, 6, 7 or 8)
Stop Bits (1 or 2)
Parity (none, odd, even, mark, or space)
Xon/Xoff (enable/disable) -- allows the Scheduler™ to respond to transmit/ no transmit commands from an external device. Usually Xon/Xoff is used in the Disable mode.

B. ENTER - Flags Selection. Use the up and down arrows and the ENTER key to select:

SUN LOW ERR - (Disable or Enable). When this option is enabled, the Scheduler™ rejects any samples where the indicated sun light reading is below 65%. When this option is disabled, the Scheduler™ will take readings at all times.

DATA LOGGER - When this feature is enabled, ALL the samples collected will be transmitted through the RS-232 port for external recording by another RS-232 device. The automatic 10 minute time-out feature is disabled when this feature is enabled.

DISPLAY - Select ^{o}C or ^{o}F for the indicated temperature.

PRINT - Begins transmitting the memory file to a printer or computer. The data will not transmit if a computer or printer is not hooked up. To end a print sequence when a printer or computer is not looked up, press ENTER. Note: This is the only pathway to the ERASE MEMORY option. After the Print sequence is finished or aborted, the erase memory option will appear.

IV. Main Program

Turn machine on. Press ENTER.

1. Select field number: The field number ranges from 1 to 240. Select a field number by using the Up and Down arrows and the ENTER key. The DEL (delete) key can be used to correct mistakes. Note that each position of the field number is selectable.

2. Select Crop: Your Scheduler™ is programmed with up to seven crops selected when the unit was ordered. Once selected for a given field, the crop assigned to a field will remain until you choose to change it. If a baseline has two parts, it will be indicated by a 1 or a 2.
   1 = pre-heading 2 = post-heading

3. Set Time: To reset the Date and time, press CALC and use the ENTER and Up and Down arrows.

4. Review Field History: Press CALC. This shows the last set of data taken on this field. Field data is retained in memory until you choose to erase the memory.

5. Begin Sampling: Press ENTER. If the message, "Sample this field again today?" appears, it means you must now decide whether to keep or delete the stored data for a field. This message will appear whenever a field has stored data. To avoid seeing this message when collecting data, it is necessary to clear the memory first. See the Print option for a description of how to do this.

V. Data Collection

A 94-second countdown will always apear whenever it has been more than 10 minutes since data was last taken. The sensor gun should not be in the holster during the 94 second countdown. This will assist the air temperature and humidity sensors in equilibrating.

The Data Screen

Before the first data point is taken, the crop temperature and air temperature readings are "Alive", meaning they will display the real time readings of these sensors. In this mode, the Scheduler™ can be used as a normal infrared thermometer to scan the temperature of a surface (or observe the temperature the ambient air). Note, this mode will work for 10 minutes. If no data are taken, the unit will shut itself off.

To collect data, press the trigger or the ENTER button. Data are sampled in bursts at the rate of 4 samples per second. The data screen displays the last sample in a burst. After the data are collected (maximum of 55 samples per burst up to a total of 999 samples), the message "Calculating" appears. The more samples in a burst, the longer the calculating delay.

The data screen contains the following information:

SAMPLE - The total number of samples (up to 999).

STD - The standard deviation of crop temperature (^{o}C or ^{o})F

CROP - Crop Temperature (^{o}C or ^{o}F). The temperature displayed assumes an emissivity of 1.0.

RH - Relative Humidity (%)

AIR - Air Temperature (^{o}C or ^{o}F)

SUN - Approximates the value of direct beam solar radiation in mW/cm^{2}. The Sun reading saturates at a value of 100. This reading can also be interpreted as the percent of direct beam sunlight available.

INDEX - The CWSI value, multiplied by 10, for the crop name given at the top of the screen. The baselines used and the calculation procedures used are proprietary. They are based on the IDSO CWSI style. Modifications to IDSO's procedure have been made to allow for improved response at low VPD values.

VPD - The VPD value (kPa). All values displayed are the last sample value in a burst. This holds a sample on the screen for recording by hand or for in-field analysis.

When you have collected all the samples for a given field, press CALC to see the average of all parameters collected.

At this point, you have two options.

1) Press CALC again. This automatically increments the field number. The crop will be whatever this field has been previously set to. It is not possible to change the crop using this mode. The sensor gun does not turn off; you are ready to start another sample sequence: PULL the trigger to sample; press CALC to average; press CALC to start a new field. The data averages are automatically stored. All data points sampled can be captured by attaching an external RS-232 device (such as a polycorder) and enabling the data logging provision. Although data capture is very rapid, you will note that data calculation and transmition seem slow. This is caused by the large number of calculations performed on the data.

2) Press ENTER. This returns you to the main menu. You can select any field or crop combination. The sensor gun should turn off.

VI. Operating Suggestions

1. Keep the sensor gun out of the holster at all times during use. The holster has its own microclimate.

2. Keep the sun from directly shining on the right side of the senor gun. It is possible for sunlight to shine directly on the air sensor, producing an error.

3. Minimize the exposure of the gun to large step-changes in ambient conditions. If the gun case is more than 15^{o}F hotter or colder than the ambient, the aspiration fan may not be able to remove all the bias caused by heat transfer between the case and the sensors. The closer the gun case remains to ambient temperature, the better.

4. Do not point the sensor gun at the sun. This can damage the IR detector (it overloads the detector). Remember, the sun has an apparent temperature of 6035^{o}C (11,000^{o}F). The Scheduler^{TM} IRT detector saturates when a target is plus or minus 150^{o}C (270^{o}F) from ambient.

5. Aim the sensor gun properly. The equations for calculating your spot size are simple. Use them to make sure you are not seeing sky. NOTE: when the sky near the horizon is seen, the indicated reading will be near ambient. When the sky several degrees above the horizon is seen, the indicated IR will be very cold, depending on the degree of cloud cover and the moisture content of the air.

6. Do not get moisture in the nose of the sensor gun. Some electrical circuitry is exposed and could be damaged.

7. Clean the lens of the IRT with ethanol that does not have denaturing additives (the additives leave a residue), or use a camel's hair brush (from an art or photography store), or with a damp cloth and a mild detergent (use distilled water).

VII. Sensors

Infrared Thermometer - Operates in the 8-14 um interval with an 8 degree total FOV. Designed and manufactured by Standard Oil Engineered Materials Company This infrared thermometer is a D.C. infrared thermometer. It does not have a mechanical chopper to compensate for changes in the temperature of the detector. Compensation is achieved by, 1) software analysis of the detector and, 2) internal thermal design. The IRT has been designed to operate within specifications as long as the internal temperature of the IRT is not changing more rapidly than $1^{o}C$ per minute. This condition will not be exceeded unless the instrument is exposed to a step-change of $20^{o}C$ ($36^{o}F$) in ambient conditions. When a step-change of this magnitude occurs, a waiting period of up to 20 minutes may be required for the instrument to operate within specifications.

Air Sensor - A thermister accurate to $0.1^{o}C$. Thermal interferance from the case reduces this accuracy to $0.2^{o}C$. IRT Case temperature should be within 15^{o} of ambient to minimize thermal interferance.

Relative Humidity Sensor - Resistance change through a bulk silicon polymer. A thermosetting resin is used which provides excellent stability. The silicon polymer protects the sensing elements from direct contact with most pollutants, including dirt. This polymer, while protecting the sensor and preserving its calibration, reduces its time response. It takes 3-5 minutes for this sensor to equilibrate to large step-changes in humidity (e.g., 20% to 60%). This should pose no problem for normal field use.

Sun-light - Two photo-diodes, wired in parallel, off-set an angle of 120^{o}. The diode outputs remain approximately constant as the solar elevation angle changes, under sunny conditions. The output of the diodes responds to changes in solar intensity caused by clouds. In the current software, the sun reading is not used in the index calculation. It is currently used as a data-quality feature. If the sun reading is below 65, readings will be automatically rejected. This feature can be disabled.

APPENDIX II

Transmitting data to a computer.

the cable supplied with the Scheduler™ has the following configuration:

Pin #	Function
1	Case Ground
2	Receive
3	Transmit
7	Signal Ground
8	DTR Out
20	DSR In

To connect the Scheduler™ to most serial printers, the cable supplied with the Scheduler™ should be adequate.

To transmit Scheduler™ memory files or data to an IBM P.C., it is necessary to make a straight through cable with pins 6 and 8 jumpered.

To transmit Scheduler™ memory files or data to a polycorder, an adapter is needed.

Scheduler Pins	Polycorder Pins
1, 7	7
2	2
3	3
6, 8	No Connection
20	25

Software

The following commands will allow you to transfer your data to the IBM (The Scheduler™ must be attached to a COM port).

IBM

1) Mode COM X: 12, N, 8, 2 (X is the Com port number)

2) Copy COMX < File Name > Name your file

3) Configure the Scheduler™ as follows (using the PRINT option):

   Baud 1200
   Char. Size 8
   Stop Bits 2
   Parity None
   Xon/Xoff Disabled
   Sun Low Disabled or enabled

4) Execute the PRINT option.

5) All data (including headers will be transferred). A CTRL-Z is sent at the end of file to return the IBM to normal operation.

Polycorder

Software for down-loading the Scheduler™ to a Polycorder is being developed.

APPENDIX I

Calculating the spot size of an IRT

F_2 = (FOV/2) The IRT in the Scheduler™ has an 8^o FOV at the extremes, about 6^o FOV at the half power points.

H = Height of IRT above the crop canopy

D = Horizontal distance from the IRT to the target.

S = Short axis of the spot size. The distance from the target back toward the observer to the edge of the FOV.

L = Long axis of the spot size. The distance from the target away from the observer to the edge of the FOV.

K = Indicator of whether or not sky is seen. If K is positive, no sky is seen. If K is negative, sky is seen. If K is between -1 and 0, the error is probably small. For calculation purposes, if K is less than 0.001, set K=0.001, or the trigonometric functions used will blow up. If K is less than -1, the IRT readings will be seriously biased by sky temperature.

W = Maximum width of the spot size

Calculations

All trig functions are in degrees. The example given is for a FOV of 6^{o}, height of 4 ft. and target distance of 25 ft.

*F_2 = FOV/2

1) $Z = (D^2 + H^2)^{1/2} = (16 + 625)^{1/2} = 25.3$

2) $G = \text{Sin}^{-1}\left(\frac{D}{Z}\right) - F_2 = \text{Sin}^{-1}\left(\frac{25}{25.318}\right) - 3 = 77.9$

3) $C = 90 - F_2 - G = 9.09$

4) $S = \frac{Z \sin(F_2)}{\sin(G + 90)} = 6.3$ ft.

5) $K = 90 - G - 2F_2$, If $K < 0.001$, then $K = 0.001$
If $K < 0$, Then "sky is seen"
If $K < -1$, Then "Do not use at this angle"
For this example, K = 6.1

6) $L = \frac{Z \text{ Sin } (F_2)}{\text{Sin } (K)} = 12.5$ ft.

7) T = TOTAL length of spot size = L + S
= 18.8

8) $W = 2 Z \tan(F_2) = 2.6$ ft.

9) Total area viewed = 3.14159 TW/4
= 39.2 $ft.^2$

POTATO IRRIGATION SCHEDULING

USING A

CROP WATER STRESS INDEX

CWT VALUE EQUATION

PRICE = BASE PRICE + INCENTIVES

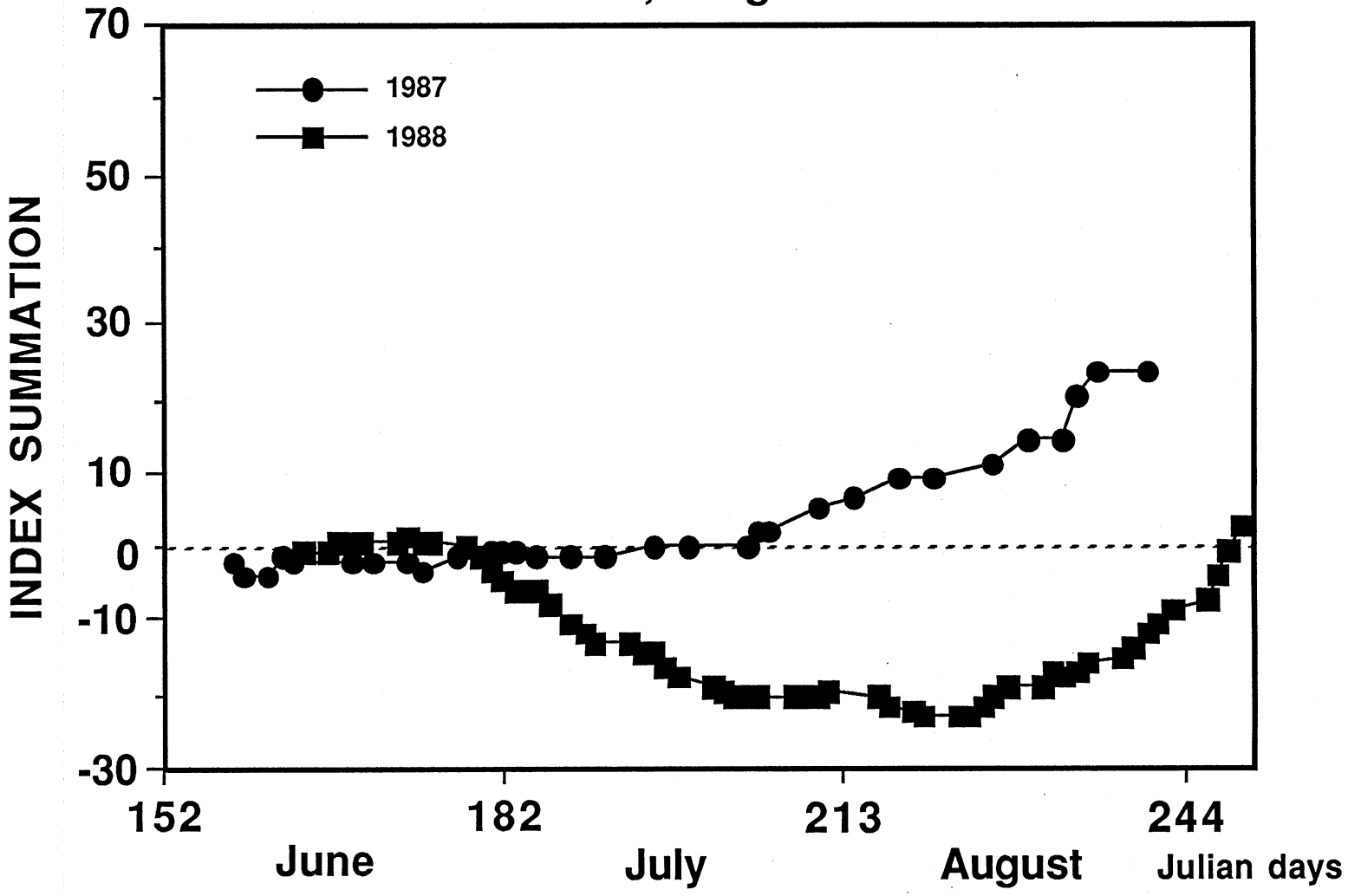
+ (% #1 - 50) x $0.02
+ (#1 + % #2 - 22) x 0.02
+ (Sp. Gravity - 1.077) x 1000 x 0.01
+ (4 - (% #3 + % #4)) x 0.01
+ (2 - % Rot) x 0.01

REJECTION CLAUSES

If % #1 grade < 20, then value = 0
If Sp Gravity < 1.077, then value = 0
If (% #3 + % #4 dark ends) > 10%, then value = 0
If % rot > 6, then value = 0

ACCUMULATED INDEX TRENDS FOR TOP VALUE POTATOES, 1987 & 1988

Malheur Experiment Station, Oregon State University
Ontario, Oregon



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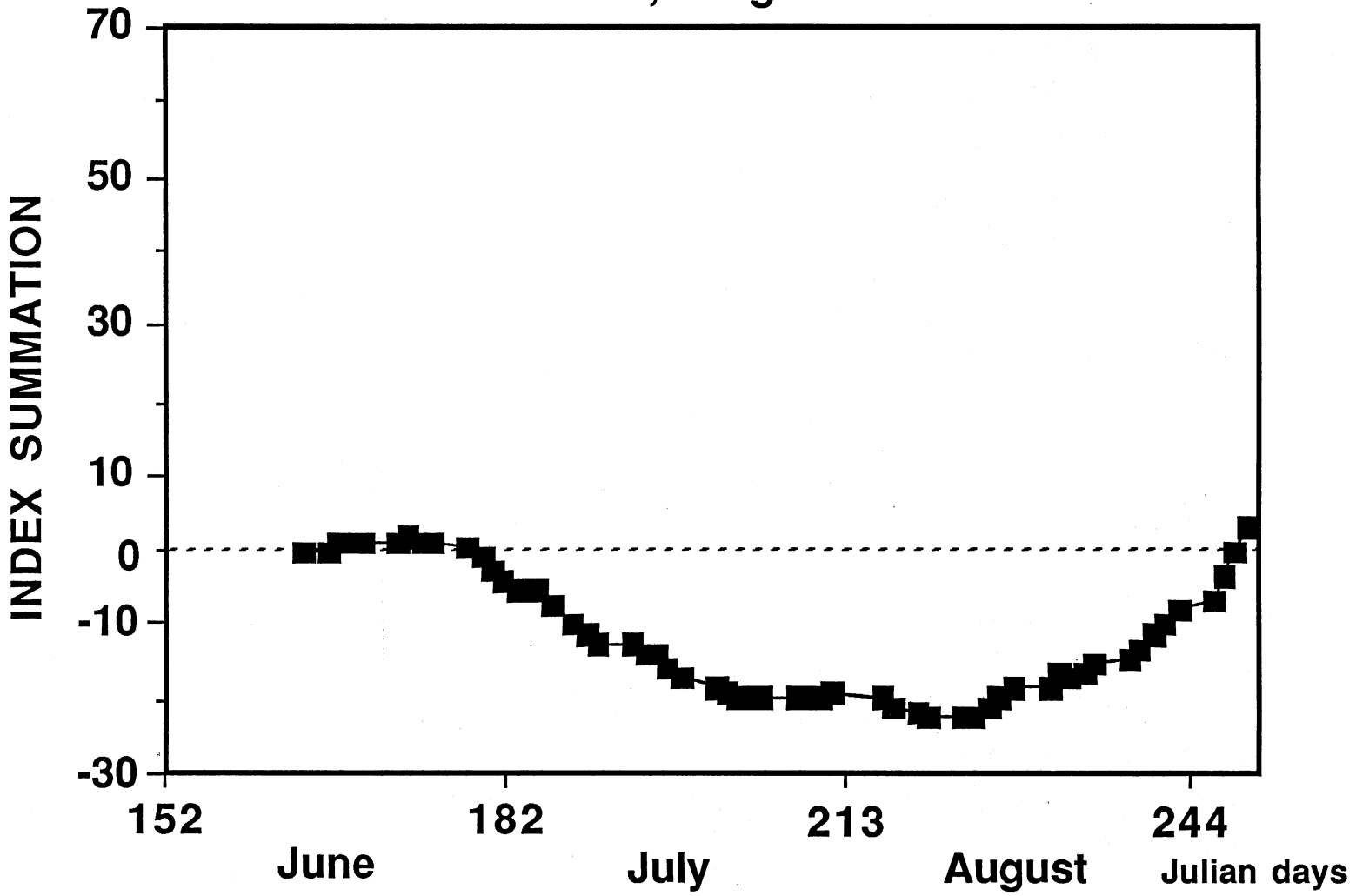
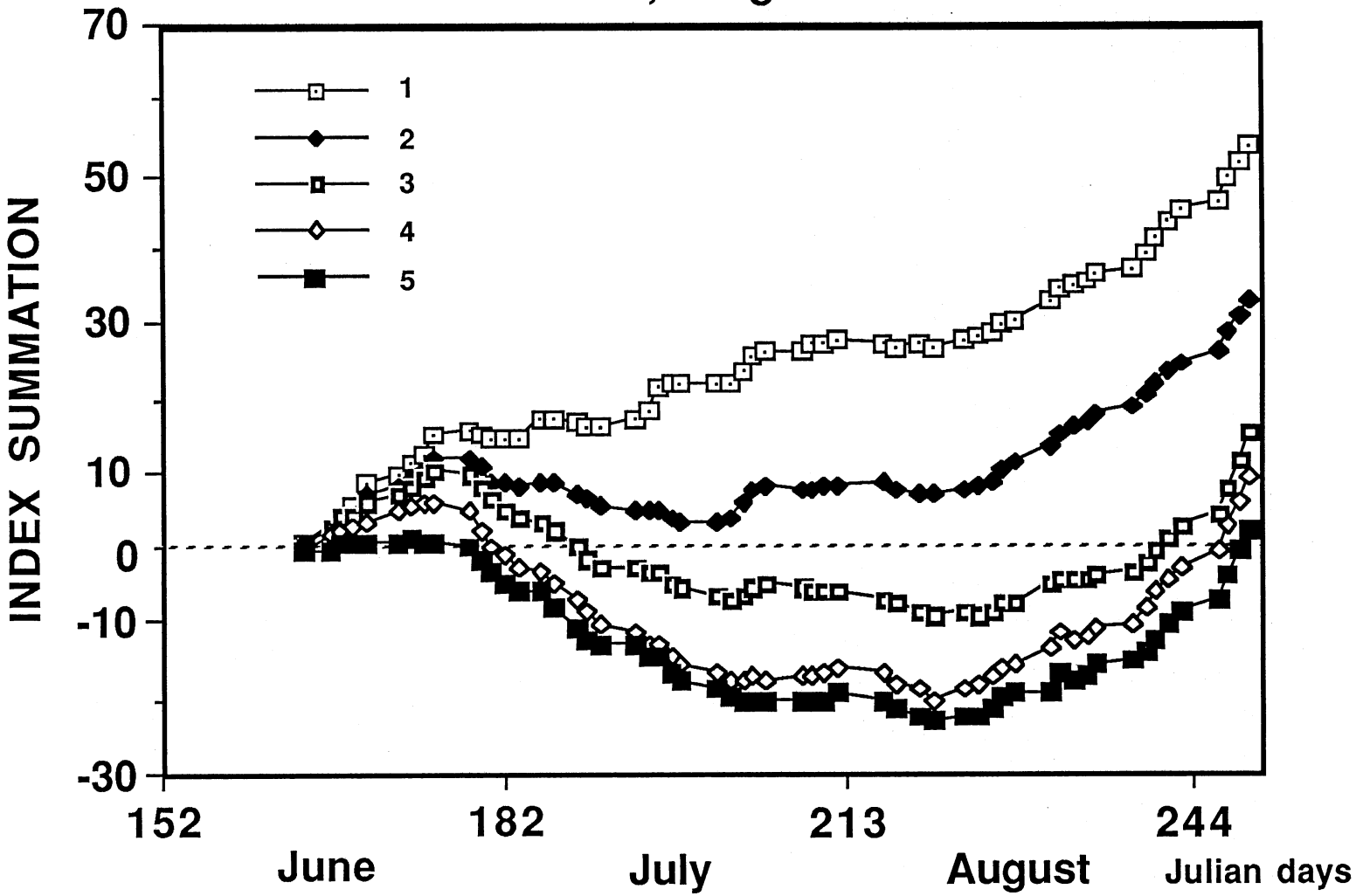
Malheur Experiment Station, Oregon State University
Ontario, Oregon



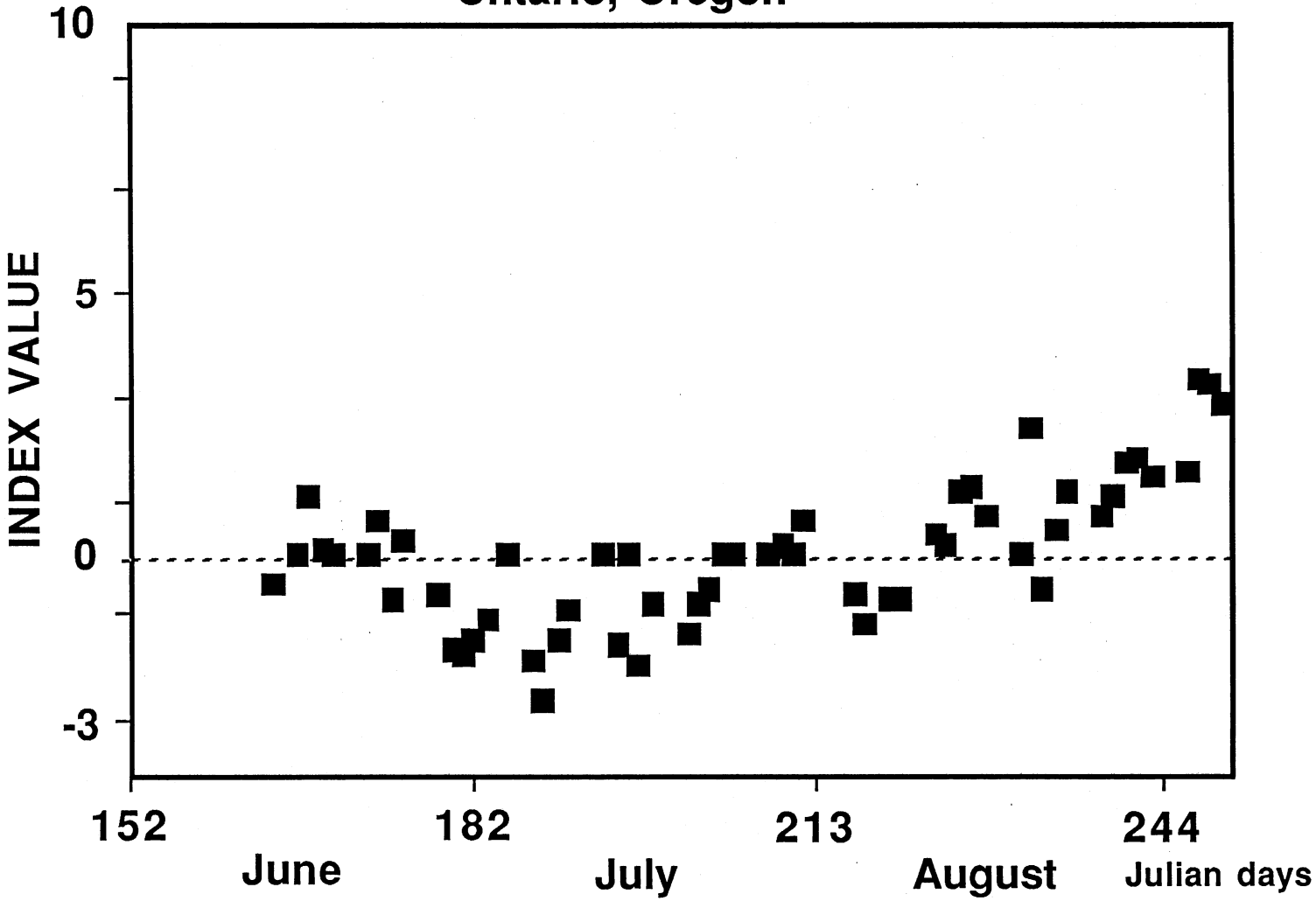
ACCUMULATED INDEX TRENDS FOR PRICE RANKINGS, 1988

Malheur Experiment Station, Oregon State University
Ontario, Oregon



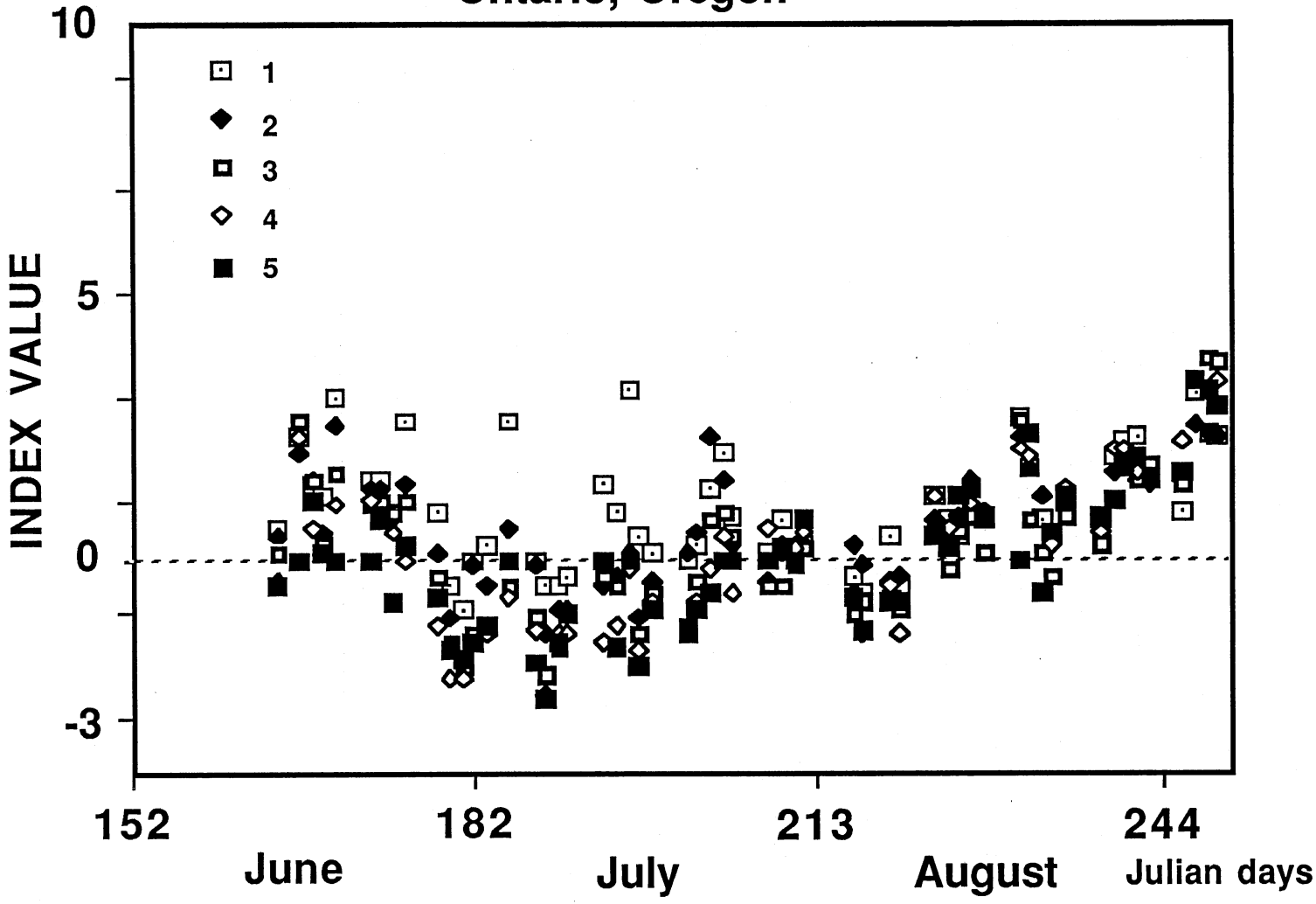
DAILY INDEX TRENDS FOR THE MOST VALUED POTATOES, 1988

Malheur Experiment Station, Oregon State University
Ontario, Oregon



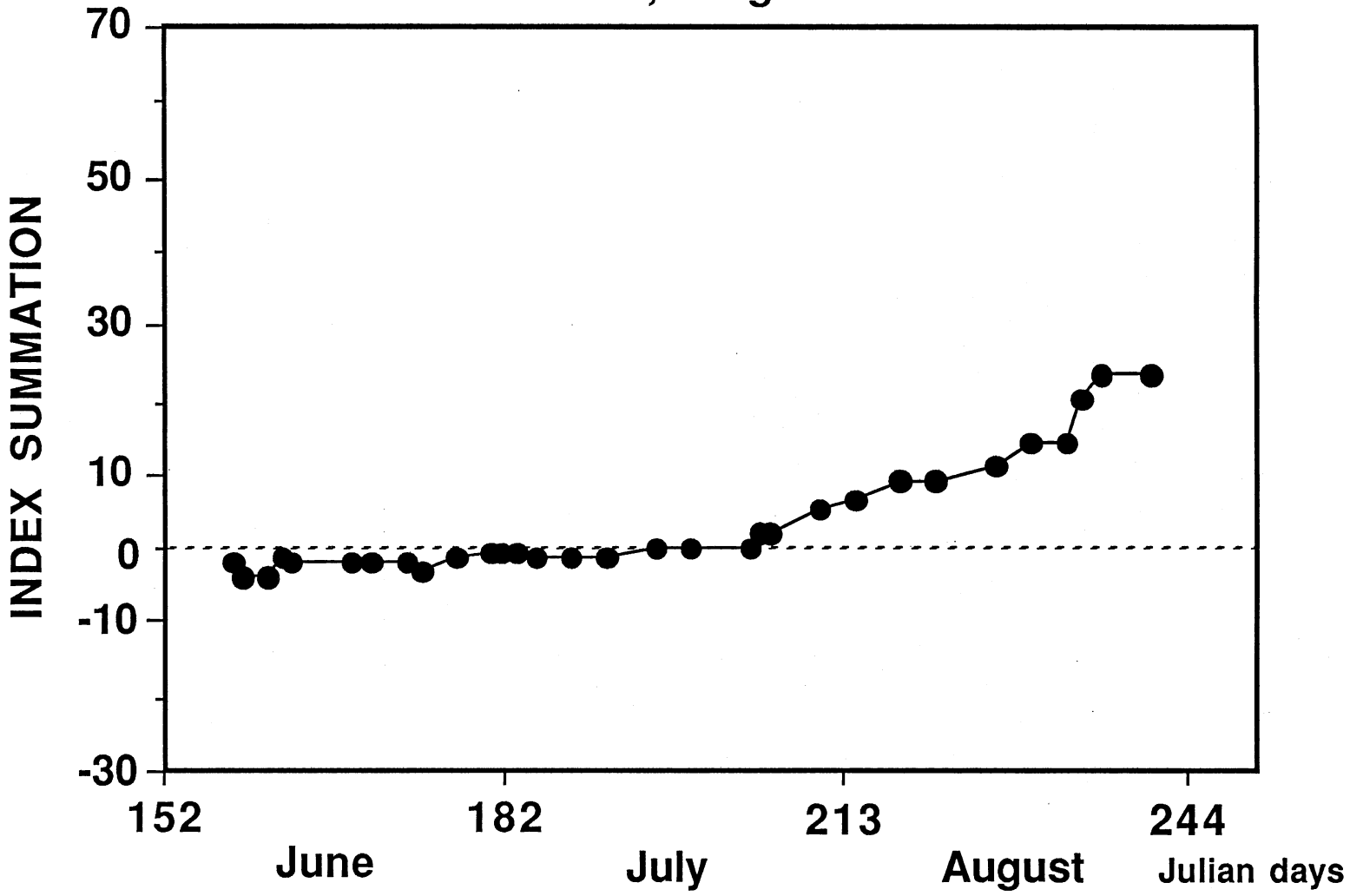
DAILY CWSI TRENDS FOR PRICE RANKINGS
1988

Malheur Experiment Station, Oregon State University
Ontario, Oregon



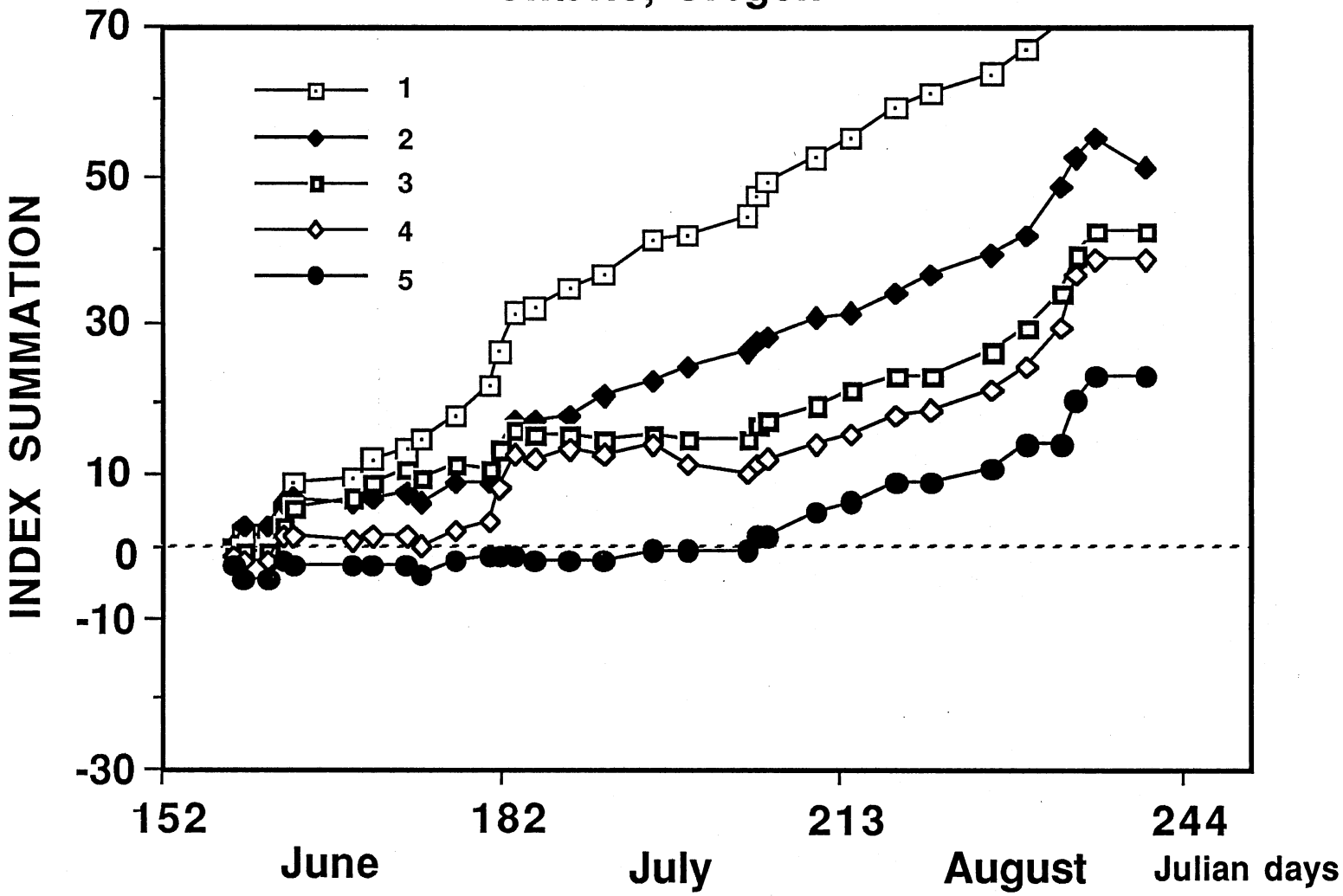
ACCUMULATED INDEX TRENDS FOR TOP VALUE POTATOES, 1987

Malheur Experiment Station, Oregon State University
Ontario, Oregon



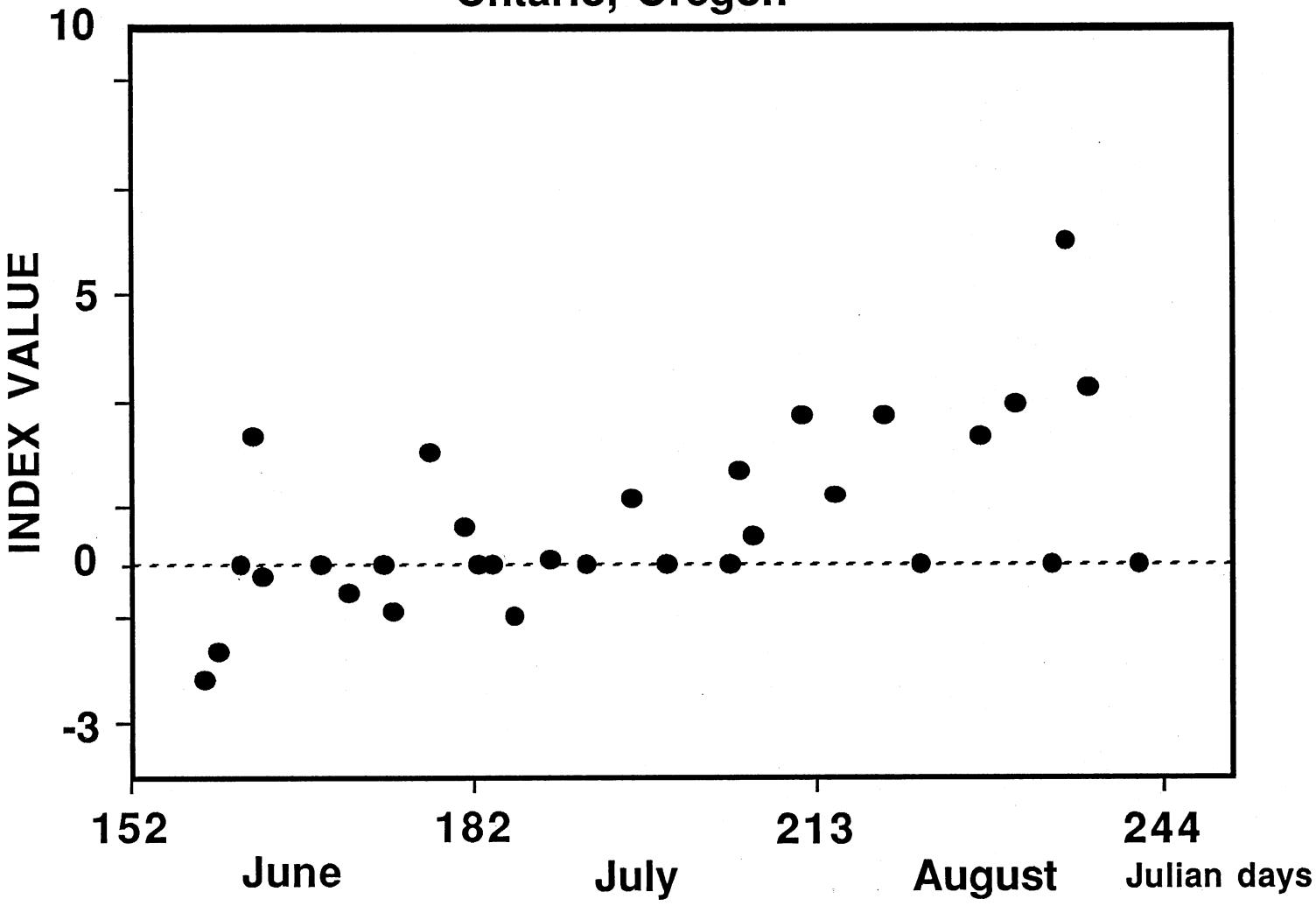
ACCUMULATED INDEX TRENDS FOR PRICE RANKINGS, 1987

Malheur Experiment Station, Oregon State University
Ontario, Oregon



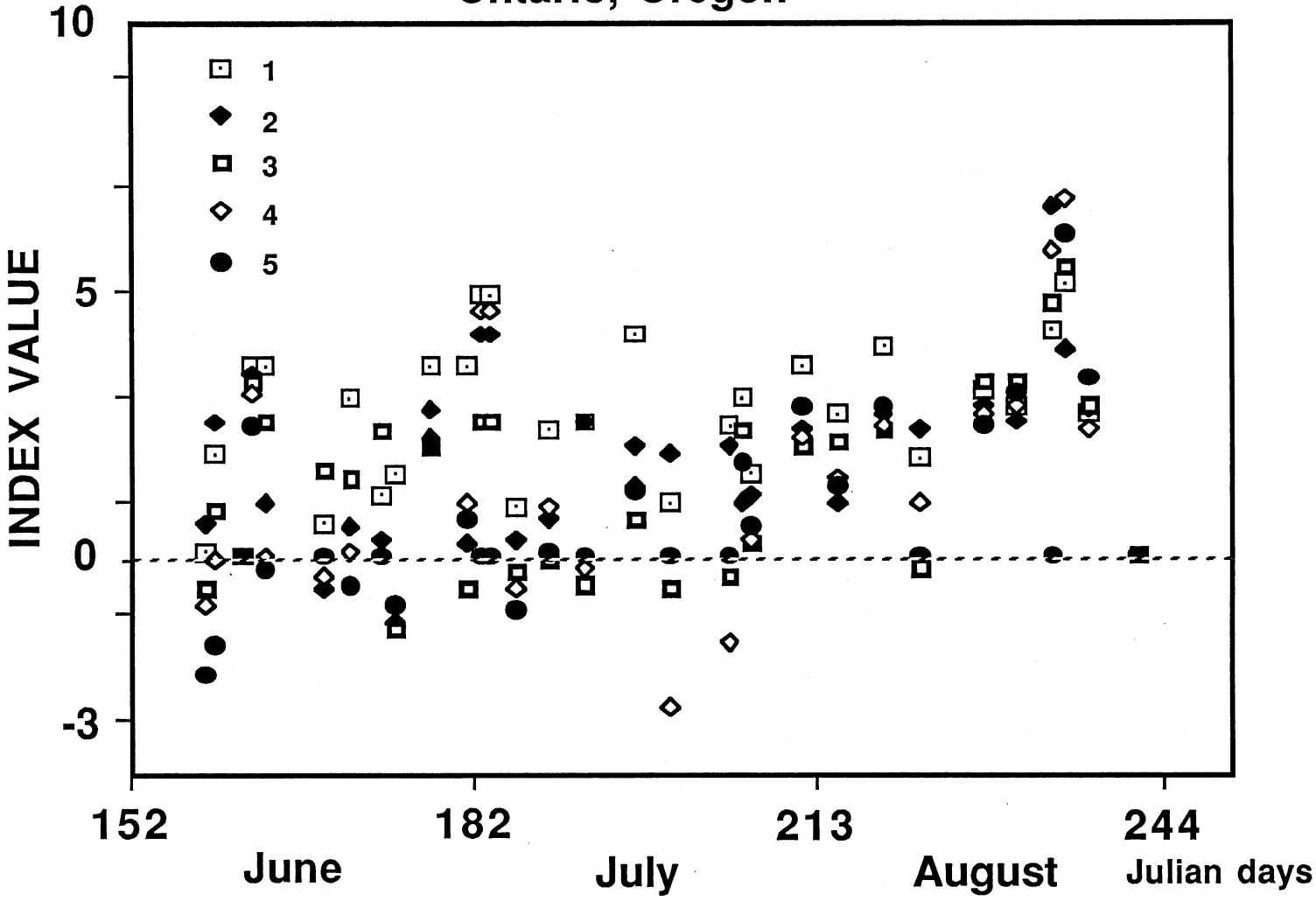
DAILY INDEX TRENDS FOR TOP VALUE POTATOES, 1987

Malheur Experiment Station, Oregon State University
Ontario, Oregon



DAILY CWSI TRENDS FOR PRICE RANKINGS
1987

Malheur Experiment Station, Oregon State University
Ontario, Oregon



CATEGORY	1987	1988
1	$3.45*	$3.83*
2	$4.27*	$4.29*
3	$4.53*	$4.57*
4	$4.83*	$4.87
5	$5.14*	$5.07

* Could have been rejected according to contract terms.

AGRONOMIC RESULTS- 1988

CATEGORY	TOTAL YIELD cwt/acre	US NO. 1	US NO. 2	SPECIFIC GRAVITY
1	598	20%	46%	1.078
2	664	25%	51%	1.080
3	610	35%	42%	1.083
4	601	46%	34%	1.084
5	621	54%	26%	1.085

AGRONOMIC RESULTS- 1987

CATEGORY	TOTAL YIELD cwt/acre	US NO. 1	US NO. 2	SPECIFIC GRAVITY
1	418	25%	47%	1.079
2	455	48%	31%	1.082
3	425	51%	25%	1.085
4	450	58%	21%	1.085
5	436	64%	16%	1.085

CATEGORY	CONTRACT VALUE (per cwt)
1	Less than $4.14
2	$4.14 - $4.44
3	$4.44 - $4.70
4	$4.70 - $4.96
5	More than $4.96

Manual Revisions

Scheduler™ Plant Stress Monitor Owner's Manual

This manual helps make the setup, day-to-day operation, and maintenance of your Scheduler Plant Stress Monitor quick and easy. The manual takes you step-by-step through each procedure, with photographs and illustrations to guide you.

First, read the section of the manual titled *Meet The Scheduler Plant Stress Monitor.* You'll find practical tips on how to get the most out of your Monitor.

IMPORTANT! This sign is used throughout the manual to indicate information critical to the successful operation of the Monitor.

Manual Outline

- ☐ **Meet the Scheduler Plant Stress Monitor.**
- ☐ **Chapter 1 — What the Scheduler Plant Stress Monitor Can Do.**
- ☐ **Chapter 2 — What the Plant Stress Index Is and How It Helps You Achieve Healthier Crops.**
- ☐ **Chapter 3 — Using Your Monitor and Analyzing Your Results.**
- ☐ **Chapter 4 — Other Monitor Features.**
- ☐ **Chapter 5 — Using a Printer With Your Monitor.**
- ☐ **Chapter 6 — Care and Maintenance of Your Monitor.**

Standard Oil Engineered Materials Company

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SENSOR GUN JACK
RESET BUTTON
INFRARED THERMOMETER
AIR TEMPERATURE
& RELATIVE HUMIDITY SENSORS
SOLAR RADIATION SENSOR
TEMPERATURE BAR GRAPH

Meet the Scheduler Plant Stress Monitor

The Scheduler Plant Stress Monitor combines the latest in agriculture technology and computer know-how into a small, portable unit that takes the guesswork out of irrigation.

Point the Sensor Gun at a field of corn, sorghum, or a number of other agricultural or vegetable crops. Then pull the trigger. The Monitor automatically measures crop temperature, air temperature, sunlight level, and humidity. Then the 64K microprocessor takes over, analyzing the data to give you an instant report on the state of your crop — it tells you if it's too wet, too dry, or within acceptable limits.

When used properly, the Monitor detects plant stress brought about by too much water or too little water long before it is apparent to the eye and in plenty of time to take corrective action. The result is healthier crops, often a savings in both water and fuel, and a dollar savings for you.

Scheduler Plant Stress Monitor Features

- ☐ Portable, battery operated. Total weight 8 lbs.
- ☐ Sensor package for measuring crop environment and crop canopy temperature. Sensor Gun bar graph for helping locate problem areas (hot spots).
- ☐ 64K microprocessor, control panel with soft-touch controls, LCD display screen.
- ☐ External outlet for connecting printer or other PC-based equipment. Connecting cable.
- ☐ Soft Cordura carrying case with shoulder strap.

R/D Consultant Model

The Scheduler Plant Stress Monitor comes in two models — the Production Model and the **R/D Consultant Model.** The **R/D Consultant Model** is a special edition designed for crop consultants and agriculture research applications. Special features are:

- One-day memory for 200 plot locations, with rapid access to plot information.
- Print feature downloads location averages for all measurements and calculated values.
- Displays Vapor Pressure Deficit (VPD) and the standard deviation of crop temperature in addition to the regular measurements programmed into the Monitor.

What the Scheduler Plant Stress Monitor Can Do

The Scheduler Plant Stress Monitor is a management tool that allows the best crop manager to become even better:

- The Monitor has a capacity of tracking up to 30 separate crop fields, and providing up to 100 samples per field.*
- Its microprocessing capability lets you store measurements in memory for up to two weeks.*
- A single measurement can view over 500 times the sample area of a single tensiometer or soil probe reading.
- Multiple observations are easy and improve sampling accuracy.
- You get on-the-spot results of your sampling.

*Note: The **R/D Consultant Model** will Monitor up to 200 fields, with a one-day memory.

Soil Probes

If you use the Monitor in conjunction with soil probes or other soil moisture sensing devices, it will provide even more insights into soil moisture levels, reserves, and irrigation timing.

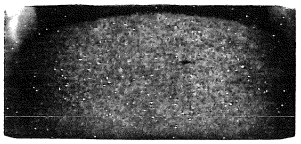
Spotting Insect Damage and Crop Disease

The Monitor is useful in spotting crop diseases and insect problems. How? The Monitor reacts to any problem that reduces a plant's transpiration rate. This reaction is *usually* caused by the lack of soil moisture, but if that can be ruled out as a possible cause, then insect damage or crop disease can be the culprit. These areas usually appear as "hot spots" (easily identified with the Sensor Gun), that can later spread throughout a field.

Non-Plant Uses

The Monitor can be useful in ways other than plant monitoring. It really depends on your operation — and your imagination. For instance, it can be used to measure surface temperature of walls, animals, or grain. If you need to know surface temperatures, air temperatures, or humidity of just about any environment, the Monitor will tell you.

The Scheduler Plant Stress Monitor must only be used in air temperatures above 50° F (10° C). The sensors have been designed to operate between 50°F and 140°F. The unit should be operated within these limits for maximum efficiency.



How The Schedules HELPS

- ☐ Allows you to Sample Large Acreages. FAST. (~~Samples Can Sample~~ average 8 5006ft² per second.)
- ☐ Increases MANpower efficiency. One person can Monitor the Acres previously Sampled by several.
- ☐ Increases crop uniformity. ~~By~~ Adjusting Irrigation Schedules to Keep crop stress uniform, regardless of Soil type.
- ☐ Increases your confidence. By Sampling Key areas, you will Know the status of ~~the~~ your crop.
- ☐ Provides you with documentation. You can easily track your crop daily, weekly, monthly or for the entire season. These Reports can be Saved for future use.

What a Plant Stress Index Is and How It Helps You Have Healthier Crops

Changing conditions can affect plants. Years of extensive agricultural research have been devoted to the monitoring of plant stress. The plant stress index calculated by the Scheduler Plant Stress Monitor is a product of that research.

Plants, like humans, react differently under different environmental circumstances. With a plant, the canopy temperature is a key indicator of how it's reacting to the local environment. When this surface temperature is compared to air temperature, relative humidity, and sunlight level, you can determine a plant's stress status. This is what the Monitor measures and analyzes.

In the field, the Monitor compares the temperature of a plant to its total environment, measuring and analyzing:

- Relative humidity
- Air temperature
- Plant temperature
- Sunlight intensity.

These measurements are used by the microprocessor to calculate the plant stress index. The result is a quick, accurate measurement of crop stress status. Knowing this helps you anticipate irrigation needs and analyze irrigation or rainfall effectiveness.

Within a few hours of irrigation or rainfall you can expect a reduction in the plant stress index. However, in some cases, the full reduction could take a day or longer, especially if the plant was severely stressed. This may be caused by slow water penetration or delays in regrowth of damaged roots.

In the case of severe overwatering (soil saturation), an increase of the plant stress index can occur. This is caused by lack of oxygen to the roots, which inhibits the ability of the plant to absorb water from the soil, resulting in an increase in the plant stress index.

What Does the Plant Stress Index Mean?

As calculated by the Monitor, index readings of zero (0) or below indicate a plant is extremely well watered. A measurement in the 0 — 2 range indicates that a plant is operating at top efficiency. Research indicates that, for most plant types, stress levels above 2 can cause plant performance to suffer.

Remember, good judgment is always the responsibility of the crop manager.

an expanded discussion is needed here. OR The Section should be deleted

— See next page

Custom Crop Programming

Plant types vary widely in their reaction to moisture, and one formula does not apply to all. The Monitor can be programmed to provide the stress index for many crops. The basic programmed package supplied with each Monitor determines the crop stress index for 5 specific crops. Current crops offered include:

- Corn
- Wheat
- Tomatoes
- Soybeans
- Cucumbers
- Alfalfa
- Barley
- Potatoes
- Cotton
- Sugar beets
- Grapes
- Grain sorghum

In addition to the basic package of five pre-programmed crops, the Monitor accommodates two general purpose crop settings (low and high). These can be used for tracking specific crops that might not be covered in the pre-programmed package. It is up to the user to decide what crop he wants to track, and to select the setting option accordingly (see **Using The High/ Low Crop Settings** on page 14).

Understanding
~~Points to Remember about~~
Index ~~values~~ ~~Readings~~ Values

IN general, index values FALL into
2 Major categories:

a. Index values less than Zero
~~b. Index values between 0 and +0~~
b. Index values greater than Zero.

Negative Index Values

When we calculate an index, we compare the actual temperature of the crop (measured with an infrared thermometer) with our baseline. If the actual temperature

of the crop is less than our baseline predicts, it means that the crop is cooler than expected. The index will be negative. It is normal to find that measured values of the index are 1 to 2 units below our baseline, i.e., the stress index will be -1 to -2. If the index is more negative than -2, possible explanations are:

- The crop is wet
- Sunlight intensity was too low. ~~This~~ Measurements may have been made under cloudy conditions, too early, or too late in the day.
- ~~There~~

- There is an error in the baseline. Once we have used a baseline for a while, baseline errors should not be significant. It is not hard to become accustomed to using a baseline that has an error in it. For example, the current tomato baseline consistently reads negative on healthy plants. Irrigation is needed when the index reads about 0 on tomatoes. We could adjust the baseline, but since we have learned how to use the current one, there is no need. In fact, it would confuse current users.

— A shaded area was sampled.

We strongly recommend you keep the sun at your back as a standard practice. This insures you will be looking in the direction of the maximum number of sunlit leaves. This is not necessary on some crops (such as alfalfa) but is always good practice. Make it a rule.

- You aimed too far from the point where you were standing and included the sky in your measurements. This problem is avoided by using proper aiming techniques.

- Air temperature is unusually cool, but the sunlight is bright. In this situation, the crop is also unusually cool, producing a negative index. There is nothing that can be done about this situation. There is also nothing to worry about from a water stress viewpoint. The index is right: the crop is not too hot.

- The sensor gun was too hot. The gun may have been left in a hot truck. If this happens, be sure to allow plenty of time for the instrument to cool off.

— The infrared thermometer lens is dirty. Dirt on the lens can affect your readings

Positive Index values

Positive index values occur for ~~two~~ three main reasons:

1. Because the crop is hotter than the baseline predicts (stress is present).
2. The sensor gun is cold. If the gun is stored in a cool room and then taken outside on a hot day, the index values will be too high for the first few minutes.
3. An unusually hot surface (such as dry soil) was included in the sample.

Points to Remember ~~About Negative Index~~ Values

- Clear skies and time of day are critical considerations.
- Negative index values are normal.
- Negative index values indicate no stress.
- Mistakes ~~can artificially create negative~~ produce erroneous index values.

- positive index values indicate the presence of stress. ~~The severity of stress~~

****

The normal management objective on most crops is to either have the index decrease with time, or be stable with time. An index is "stable" with time, if it stays within a zone about ~~2~~ index units wide. For example, readings would be considered stable if they remained between -2 and 0 or if they remained between 1 and 3. Many users can maintain a zone of stability with smaller limits than these, especially users who have drip irrigation systems. When you are analyzing index patterns, the key is the trend (increasing, decreasing, or staying flat).

****

Seasonal Trends

The pattern of the index between sampling dates is VERY important. Is the index increasing or decreasing or holding steady with time?

The first thing you need to know is "what's normal for this crop?"

The second thing you need to know is "how does this field compare with "normal?"

YOU MUST UNDERSTAND THE BIG PICTURE IN ORDER TO UNDERSTAND INDEX READINGS. The index for every crop has a normal pattern. For example, a row crop, such as cotton, would have a seasonal pattern like the one ~~on the next page~~. The ~~dotted~~ lines represent the upper and lower limits to normal readings. If an index value is above the upper line, the crop ~~is under stress~~. If an index value is between the lines, it means the crop is not under stress.

Reasons the index can be above normal:

Needs Irrigation

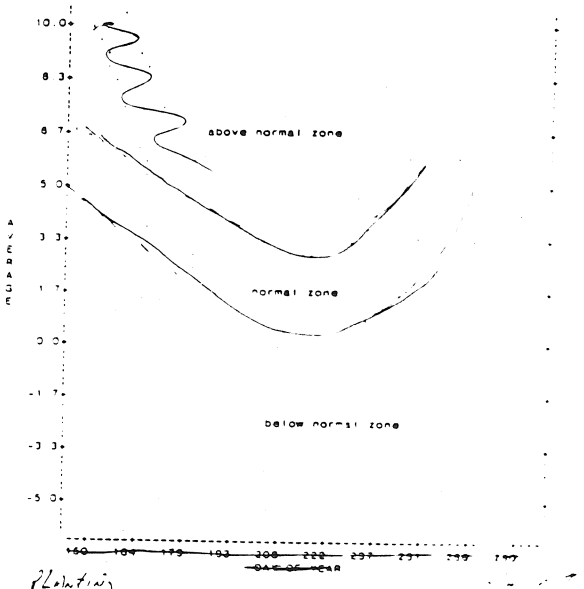
- Crop is under stress
- Sensor gun is too cold

Reasons the index can be below normal:

- Crop is wet
- Wrong time of day
- Poor aiming technique
- Unusually cool air
- Sensor gun was too hot

Points to Remember

You must know the BIG PICTURE for a crop to know what is normal.



Plotting

Sample Season Index

Chapter 3.

Using Your Scheduler Plant Stress Monitor and Analyzing Your Results

Unpacking and Setup

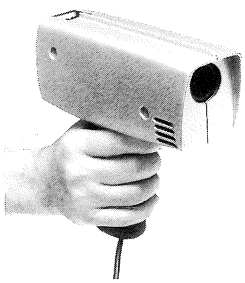
The Scheduler Plant Stress Monitor includes the following equipment:

- 64K microprocessor, contained in a durable housing with molded holster (for the Sensor Gun). Outlet port and cable for attachment to printer or compatible computer. Adjustable strap.
- Infrared Sensor Gun with attached cable.
- Soft-side carrying case.
- Battery pouch.

Assembly

The Monitor comes fully assembled and ready to take readings. There is a cover over the printer port to protect it from dirt.

Using the Scheduler Plant Stress Monitor Sensor Gun



IMPORTANT! Read this entire section carefully. Proper use of the Sensor Gun is critical to taking accurate samples.

The Sensor Gun is the sampling tool of the Monitor. Point the gun at the target plant or field, squeeze the trigger, and you get all the information necessary for the Monitor to plot the stess index.

How To Get A Good Reading

Readings must be taken looking at the sunlit side of the plant (sun at the viewer's back). **Proper use of the Monitor requires that the gun "sees" only vegetation. Bare soil, open sky, water, buildings, etc. in the gun's viewing area will result in an inaccurate reading.**

Sampling Guidelines

You want your sample to reflect average conditions. Therefore, follow these guidelines for best results:

1. The Monitor must be used during the peak sunlit hours of the day, when plant stress is most likely to occur. The recommended time to take samples in the **summer** is between 11 am and 4 pm. The time to take samples during the **winter** growing season is between 1 pm to 3 pm.

2. The plant leaf surface must be dry.

3. **The Monitor operates best under full sunlight conditions. Therefore, for best results, the area to be sampled should be in direct sunlight.**

See next page

Unless you have purposely deactivated the sunlight sensing feature (page 14), the instrument will tell you when the sunlight level is too low for a valid reading. If a cloud's shadow should pass over the area being sampled, you must wait 30 seconds after the sun reappears for the area to warm up again before a sample is taken.

4. Use the Monitor in the field. **Don't take readings from inside a vehicle or building.** The sunlight sensor on the top rear surface of the gun must be exposed to the sun when taking readings. It will not operate properly if shaded.

5. Make sure only green, sunlit vegetation is "seen" by the gun — no bare soil or horizon.

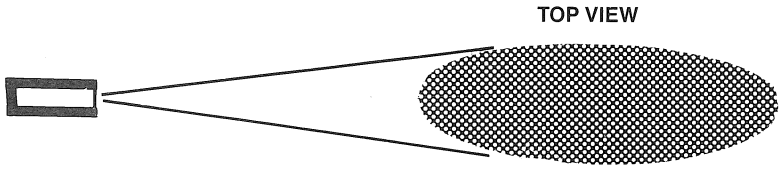
6. Air temperature extremes are likely on road surfaces, so avoid taking samples while standing on roadways.

Sampling Techniques

You can take samples one at a time by pointing the Sensor Gun at a specific area and pulling and releasing the trigger or you can "scan" an area by holding the trigger down and slowly sweeping the Sensor Gun from one side to the other. Using this method, the Gun will take readings every ¼ second, supplying a panorama of crop conditions in a broad area.

How the Sensor Gun Works

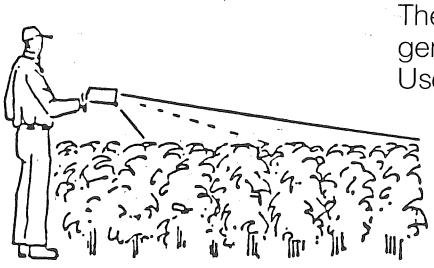
With the Sensor Gun, you simply point and "shoot". The gun "sees" a oval-shaped area (below), similar in shape to the area lighted by a flashlight. The size of this oval-shaped viewing area is controlled by how high you hold the gun above the target area, and also by how far away the target area is from the gun.



Dimensions of the Zone "Seen" by the Sensor Gun

HEIGHT ABOVE CANOPY (FT.)	DISTANCE TO TARGET (FT.)	OVAL LENGTH (FT.)	MAX. OVAL WIDTH (FT.)	AREA VIEWED (SQ. FT.)
3	10	3	1	3
3	40	48	2	120
3	75	550	5	4700
5	120	680	8	8200

The technique for using the Sensor Gun will change as a crop matures. As a general guideline, the gun should never be closer than 3 feet from the soil. Use the following guidelines when aiming at the plant target:



- 25 feet should be the limit to your aim when the Sensor Gun is positioned approximately 1 foot above the crop canopy.
- 75 feet is the limit at 3 feet above the canopy.
- 120 feet is the limit at 5 feet above the canopy.

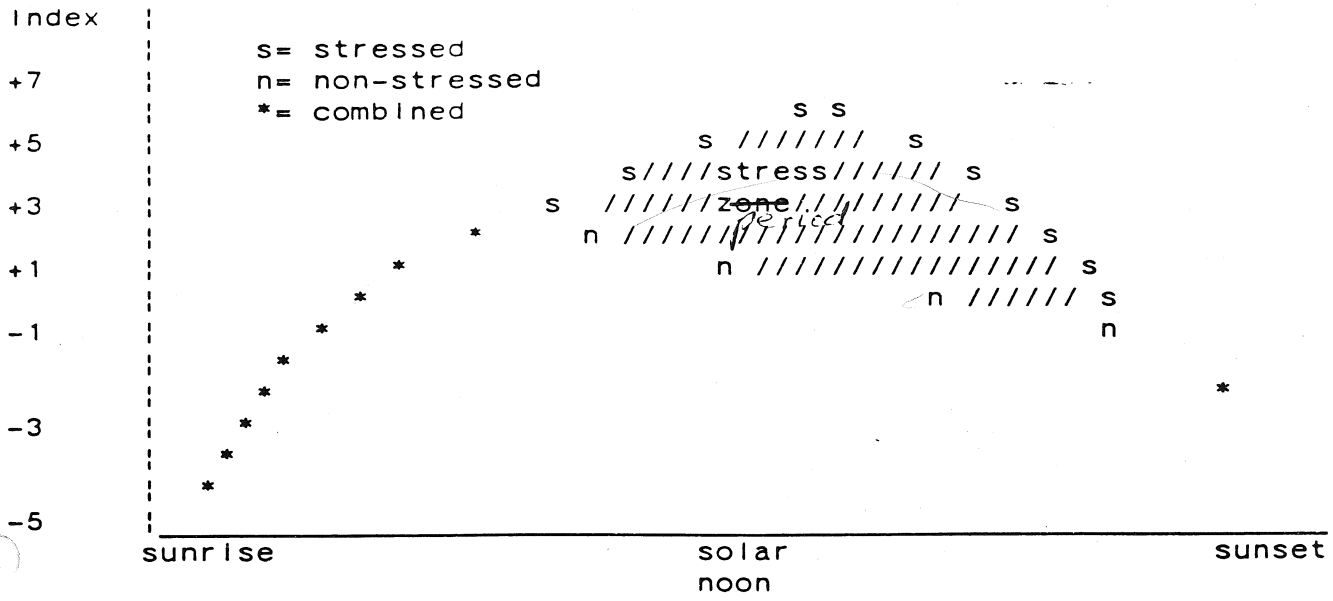
unless you are standing on a ladder or other tall structure, you should limit your aim to a spot about 30 feet away.

Chapter

Setting the Best Time of Day

Hourly Trends

The index is not constant from hour to hour. It varies with the sun. The graph below shows the expected hourly pattern for a stressed and non-stressed crop.



You should already know about sunrise and sunset, but what in the world is "solar noon?" In the Old West, another name for solar noon was "High Noon." Solar noon occurs when the sun is exactly half-way between sunrise and sunset. The sun is brightest and hottest at this time. Solar noon can occur anywhere between 12:00 p.m. and 2:00 p.m., depending on where you live and whether or not you are on daylight savings time or standard time. The easiest way to determine solar noon is to use the old Boy Scout trick of placing a stick in the ground. When the shadow of the stick points directly south, it is solar noon.

Points to Remember

Maximum plant stress usually occurs about 1 hour after solar noon. The index can be expected to change from hour to hour.

Be consistent on when you sample.

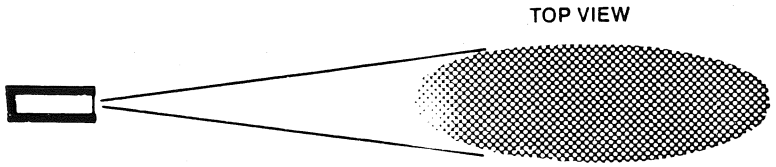
Do not sample too early or too late in the day

Aiming Techniques

- Aim at a spot at least 2 seconds before squeezing the trigger.
- Keep the sensor gun at least 3 feet above the soil
- Select a target that avoids soil, sky, shadows, wood or anything that is not green, sunlit vegetation

How the Sensor Gun Works

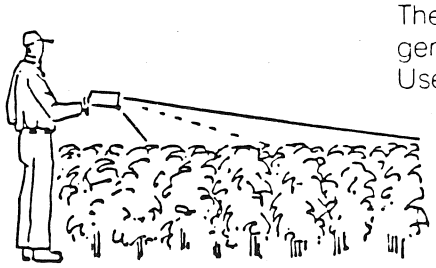
With the Sensor Gun, you simply point and "shoot". The gun "sees" a oval-shaped area (below), similar in shape to the area lighted by a flashlight. The size of this oval-shaped viewing area is controlled by how high you hold the gun above the target area, and also by how far away the target area is from the gun.



Dimensions of the Zone "Seen" by the Sensor Gun

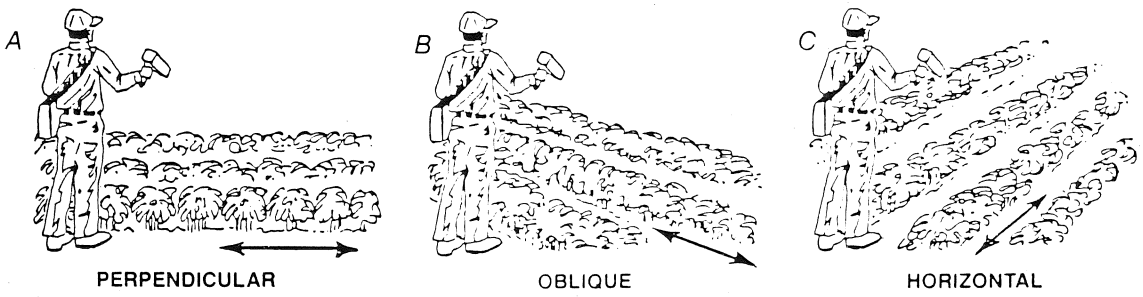
HEIGHT ABOVE CANOPY (FT.)	DISTANCE TO TARGET (FT.)	OVAL LENGTH (FT.)	MAX. OVAL WIDTH (FT.)	AREA VIEWED (SQ. FT.)
3	10		1	
3	40		2	
3	75	5	5	
5	120	6	8	

The technique for using the Sensor Gun will change as a crop matures. As a general guideline, the gun should never be held closer than 3 feet from the soil. Use the following guidelines when aiming at the plant target:



- 25 feet should be the limit to your aim when the Sensor Gun is positioned approximately 1 foot above the crop canopy.
- 75 feet is the limit at 3 feet above the canopy.
- 120 feet is the limit at 5 feet above the canopy.

There are several ways to measure a row crop, depending on the viewing angle of the Sensor Gun and the position of the sun.



(A) Across the row(s). perpendicular to row length.

(B) Across several rows. at some oblique angle.

(C) Down the length of one row.

with some crops, it may be necessary to aim at individual leaves.

Make your own sampling surface, if necessary. On small leafed crops, so for example, because, it may be necessary to "bunch" leaves to create a surface of suitable leaves to sample. Consult with your dealer if you plan to use this technique.

Consistency and aiming and effective data analysis are the keys to getting good results

Things to Expect

- When clouds move in front of the sun, the index will decrease rapidly.

- It is common to see an increase of 1-2 stress units after a flood irrigation. This pattern is caused by a lack of oxygen in the soil profile. This is especially evident in heavy soils. As drainage occurs, there is a rapid decrease in the index. It will remain low, then gradually increase until the next irrigation or Rainfall events.

R&D Models -- The Data-logger feature is sometimes left enabled by users when they begin sampling. This feature is designed to allow the Scheduler to communicate with an external computer. When "Data-logger" is enabled, the Scheduler will not take samples. Always disable the data-logger feature, UNLESS you plan to attach a computer to the Scheduler.

- The coiled cord ~~cord~~ connecting the Sensor gun and the computer can ~~cause~~ be broken. Avoid yanking, twisting or knotting the cord. Symptoms of a broken cord are

- Software locks up (~~and~~ "Data-Logger" feature is disabled on R+D models).

- Sensor Readings become wild. (for example, canopy temperatures of 300 degrees or Relative humidity of -1000%, etc.).

- Sensors become inaccurate if battery voltage decreases below 6.7 volts. The Schedule automatically will warn you when this happens.

- ~~Read~~ ~~Accuracy is enhanced by~~ ~~the~~ ~~1:~~
- ~~Keep~~ The

Suggestions for ~~Ett~~ Obtaining
~~Gett~~ Quality Information

- PLAN an ~~logical~~ appropriate sequence of fields to sample. Make measurements in appropriate ~~logical~~ locations within a field. Include in your sampling:
  - recently irrigated areas
  - areas where soil moisture is monitored
  - areas where problems may occur ~~Areas like~~ or ~~Irrigation~~ stress levels should be ~~May~~ checked.
- PLAN how you will record and use the information the Scheduler ~~gett~~ provides. Software is available to assist P.C. owners. Consult with your dealer in planning an effective sampling ~~scheme~~. Routine.

- Keep the sensor gun out of its holster until you are done. ~~With~~ Let the FAN RUN at all times (by placing the program in a data screen). When traveling between fields, ~~etc~~ you can place the bar-graph end of the sensor gun into the holster. ~~Ke~~

- Keep the sun approximately at your back.

~~- If the s~~

- When the sun is interrupted by a passing cloud, wait at least 1 minute ~~before~~ for the crop to warm-up after the sun re-appears.

- Low windspeed is preferable, (< 10 mph). When readings are made under ~~high~~ moderate (10 - 20 mph), index values may be 1-2 stress units lower than under low windspeed conditions. High windspeed conditions (> 20 mph) may cause a stress in some crops. ~~Interpretations needs to be adjusted accordingly, the~~ best ~~guide is experience~~.

- hold the gun at least 3 feet above the soil or at least 1 foot above the top of the crop. Always be consistent with your aiming technique.

O.K.

- Aim at a spot about 30 feet from where you are standing. This represents about 150 ft² square feet.

O.K.

- Aim at an area at least 2 seconds before you pull the trigger.

O.K.

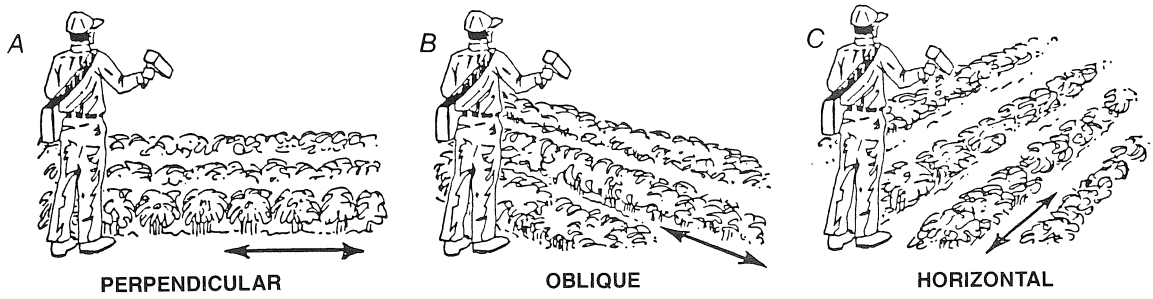
- Take 10-20 ~~samples per location~~ readings ~~in a scoop~~ per location. Sample 4-5 locations per field to get a good average. Do not take an excessive number of readings in one spot.

- At your first sample location, take repeated readings until ~~you get~~ the averages of 3 ~~consecutive~~ consecutive samples are within 0.5 index of each other.

- Measure only dry plants. Wet plants will ~~always~~ have a high ET rate regardless of soil moisture.

- Use proper aiming techniques. Refer to your KNOW-How Bulletins # & for guidelines or contact your dealer for assistance.

There are several ways to measure a row crop, depending on the viewing angle of the Sensor Gun and the position of the sun.



(A) Across the row(s). perpendicular to row length.

(B) Across several rows, at some oblique angle.

(C) Down the length of one row.

How Many Samples Should I Take?

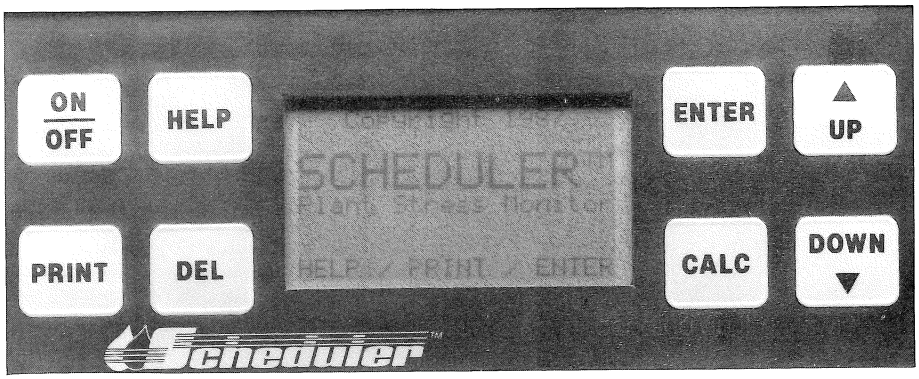
The Monitor can take many samples in seconds. Generally, the larger the area being sampled, the more readings are required. For example:

- For a field of 1 to 40 acres, 15 or 20 samples should be sufficient.
- A large field of up to 160 acres can require 20-40 samples.

Step-by-Step Operation Guidelines

Control Panel Key Functions

Take a minute to learn the key functions of the Monitor control panel.



Monitor control panel.

ON/OFF

Pressing this key once powers up your Monitor. You'll hear a beep when you press the button — the Monitor will beep every time you press a key. Pressing the **ON/OFF** button again will turn off the Monitor.

The Monitor is programmed to turn itself off if 10 minutes pass without a key being pressed. This feature does not erase information that has been recorded before shut-off.

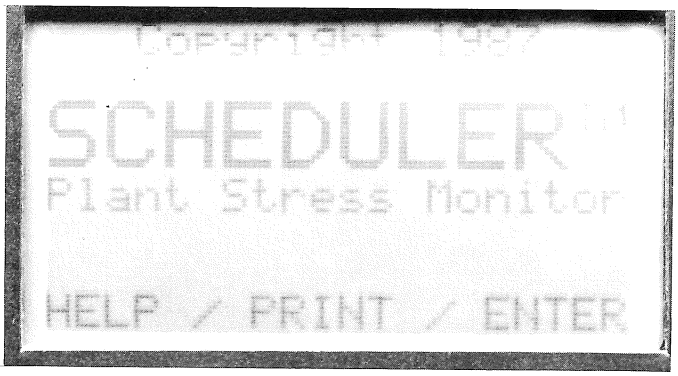
HELP

If the word **HELP** appears on the bottom of a screen, or the screen says **"Help screen available",** pressing the **HELP** key will get you step-by-step guidance and additional information.

UP/DOWN Arrows	The **UP/DOWN** arrows are used to select field number, crop choice, or adjust time and date on the screen (similar to adjusting the features of a digital watch).
ENTER	Enter field location figures, dates and times, and sample readings into memory with the **ENTER** key. The **ENTER** key also moves you through the program.
PRINT	The **PRINT** key sends information to another computer or a printer (a printer is not included in the Monitor package).
DEL (Delete)	The **DEL(Delete)** key cancels your previous selection or sample.
CALC	The **CALC** key summarizes sample data or summons historical records and graphs.

Always remove the Monitor from the fabric carrying case when you are ready to use it, and always carry the Sensor Gun in your hand while sampling. Don't return the gun to the molded holster until you move on to another field. This avoids delays for temperature adjustments.

- Press the **ON/OFF** key.* The **Main Menu** screen appears.



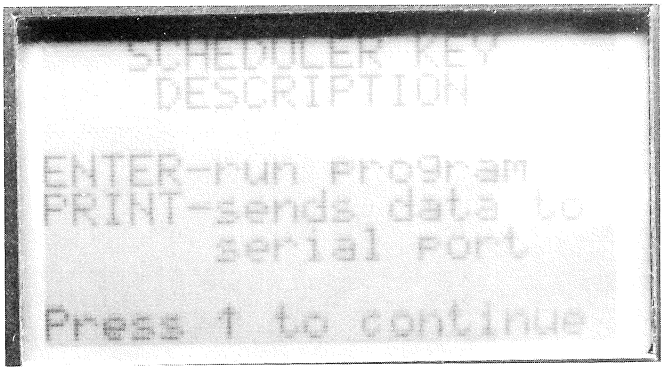
Main Menu Screen.

* Note: The Monitor gives off a series of tones (beeps) that indicate specific functions:

- One beep shows that a key has been pressed.
- •• Two beeps means that the sensors are powering up.
- ••• Three beeps indicate that a sample reading is being rejected (check the display screen for instructions).

HELP Function

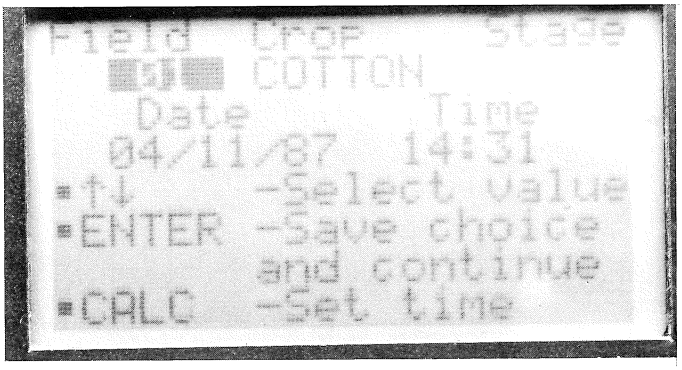
- Try the **HELP** key. By pressing **HELP,** you get the screen listing key functions for the program. To exit from **HELP,** press **HELP** again . An example of a **HELP** screen follows:



Sample Help Screen.

Field Selection Screen

- Press **ENTER** to begin. A highlighted image shows which item on the screen **(FIELD, CROP)** is ready to be entered.



Field Selection Screen

- Assign a **field identification number** to the area or field you wish to sample (from 1 to 30*). Use the **UP** or **DOWN** arrows to "count" to the number you want. This is the reference number you use when you return to that same field for additional samples on another day.
- Press **ENTER.**
- Pick your **CROP.** If you want a crop other than the one shown (**COTTON** in the screen above), use the **UP/DOWN** arrow keys to move through the available selections. Where it applies, crop stage (for example, 01 for pre-head, 02 for post-head wheat) is listed next to the crop.
- Press **ENTER.**

The Monitor files the crop and field number selected, along with any readings you take in that field. Later, when you return to that same field for additional sampling, you punch up that field number on the display and then take your samples*. This is how you construct your ongoing profile of plant conditions for that location.

* Note: The **R/D Consultant Model,** has a capacity of 200 fields. To find a field number quickly without "scrolling" through the entire numbered list, follow these instructions:

- On the **Field Selection Screen,** the three-digit number is shown as **000** with the left zero (hundreds) backlighted. You use the **UP** arrow to set the number you want. Press **ENTER.**
- The middle zero (tens) and the right zero (ones) are backlighted in turn . Follow the same procedure as with the first number.

Changing an Entry

If you have made a mistake or want to change a selection, Press **DEL.** This moves you back one step and lets you try again. A **HELP** screen is available to guide you.

Clock and Calendar

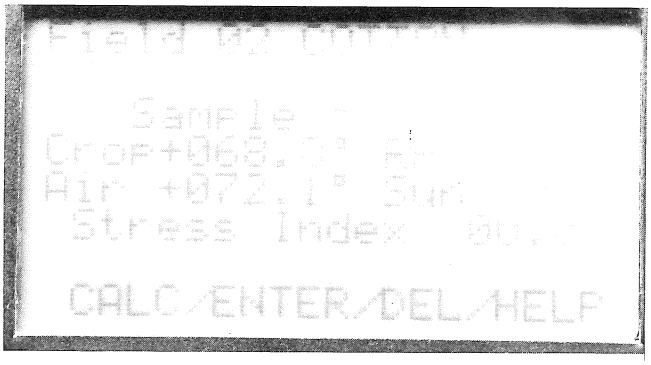
The monitor's internal clock automatically tracks date and time. The date is entered as month/day/year, and the time as hours:minutes in marine time (3:25 pm, for example, is shown as 15:25). You can adjust the clock if necessary (see page 18).

Taking A Sample

After you have entered your field number and made your crop selection, a screen will inform you:

"Press **ENTER** to begin sampling. Press **CALC** to review field history." (for more about reviewing a field history, refer to **"Reviewing Records"** on page 12).

- Take the Sensor Gun out of its holster, and press **ENTER** to activate the sensor package. You get the message, **"SENSORS POWERING UP",** and a clock appears on the screen and counts down 94 seconds. Two beeps will tell you when the Sensor Gun is ready to take samples. The **"Sample Taking"** screen appears. *



Sample Taking Screen.

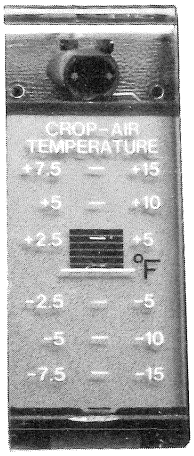
* Note: The sensors on the Sensor Gun are very sensitive to temperature variations, and can heat up when the gun is in the holster. This can result in an inaccurate reading when the gun is first taken out of the holster. An automatic delay is built into the system to allow the sensors to adjust themselves to the field environment (the 94 second delay). Therefore, sampling will go quicker if you carry the gun in your hand when you are moving from place to place in a field to take your samples.

Detecting Hot Spots

The Bar Graph on the back of the Sensor Gun was designed to quickly identify temperature variations (hot spots). **The Bar Graph only operates when the trigger is not being used.**

Use the Bar Graph on the Gun to "scan" the field and identify temperature variations and problem areas before taking any samples.

For many crops, leaf temperatures for healthy, transpiring plants are equal



to or lower than the surrounding air temperature. The **air/temp.** line on the Bar Graph represents the surrounding air temperature. The difference between that air temperature and the crop canopy temperature is indicated by the **column of bars** on the graph. In the illustration on the left, for example, the crop canopy temperature is 6° Fahrenheit higher than the air temperature.

For most readings, the difference between crop canopy and air temperatures should be within 10°F. When the difference is greater than plus or minus 15°F, it is possible that you are using the gun incorrectly. If your aim is off the target, and the gun "sees" soil, artificially high readings are the result. If you aim too high and the gun "sees" the sky, then you can get an artificially low reading.

Note: As indicated on the Bar Graph, temperature readings appear in degrees Fahrenheit (°F) on the right, and Centigrade (°C) on the left.

Taking A Reading

Aim the Sensor Gun at the target and record your reading by pressing and releasing the trigger. You'll hear a beep as the Monitor records a sample. Multiple samples can be recorded by holding the trigger down and "scanning" the target. Using this method, the Monitor will beep again and again as it records a sample each ¼ second until you release the trigger. The Monitor will record up to 100 such samples per field.

The message **CALCULATING** appears on the screen, and there is a slight delay while the Monitor records the information gathered. The length of the delay depends on the number of samples taken in one sample sequence.

Wait until the **CALCULATING** message disappears before proceeding.

Sample Averages

The data that now appear on the screen reflect your last sample. To get the average of all samples, press **CALC.** To enter your information and proceed to the next field, press **ENTER** to return to the **Field Selection** screen.

Rejected Readings

The Monitor rejects readings when the sunlight level is too low, and you'll get this message:

"Sunlight Too Low"

If this happens, press **ENTER** to return to the previous screen. You can try again to get a valid sample or wait until conditions improve (the sunlight must register at least 65% of full sun for a good sample).*

On partly cloudy days, wait until the sun is not blocked by the clouds before taking samples. When the sun shines again you must allow the crop to be in full sunlight 30 seconds before beginning to sample.

* *Note:* The solar radiation ("Sun Low Error") feature can be disabled by the user for special purpose uses of the Monitor (see page 14).

Deleting Unwanted Readings

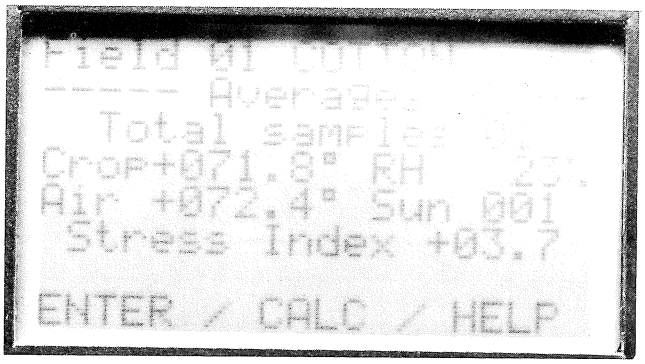
If you have taken an unwanted reading, it is important that you delete it before taking any more samples. Press **DEL** to erase your most recent sample. **You cannot delete individual readings later in the program.**

If you wait too long between samples and the Monitor automatically shuts off, you do not lose the data you have recorded. Turn on the power, and review the field history.

Your samples have been automatically averaged and calculated. If you wish to resample that same field that same day, (see **"Returning to the Same Field for Sampling,"** page 14).

Analyzing Results

- Press **CALC** when you have finished sampling a field. The **Field Summary** screen follows.



Field Summary Screen.

The stress index you see on the screen has been adjusted to be representative of the condition of the crop and field just measured. It is calculated using the averages of all the measurements recorded on the **Field Summary** screen.

At this point, you have two options:

- If you want to sample another field, press **ENTER.** This will return you to the **Field Selection** screen.

- If you want to view the graph of field summary stress indexes from the past 15 days, press **CALC.**

Reviewing Records

At any time, the Monitor allows you to review the records of the past 15 sampling days.

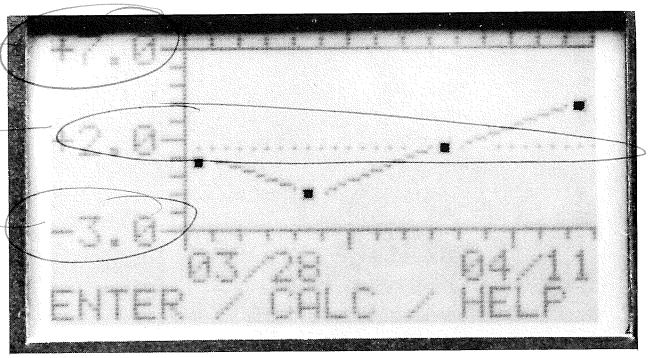
- Call up the **Field Selection** screen (page 9), and select the field number that you want to review.

- Press **ENTER** to verify the other entries on the screen, and when the screen prompts you, press **CALC** to view historical data.

If you have sampled the field that day, you will get the **Field Summary** screen. If you have not sampled the field that day, you will get the **15-day Historical Graph.**

The 15-Day Historical Graph

The Scheduler's 15-day **Historical Graph** feature allows you to Monitor stress index trends and analyze irrigation effectiveness over a 15-day period.*



15-Day Historical Graph Screen.

The Dotted Stress Index Line

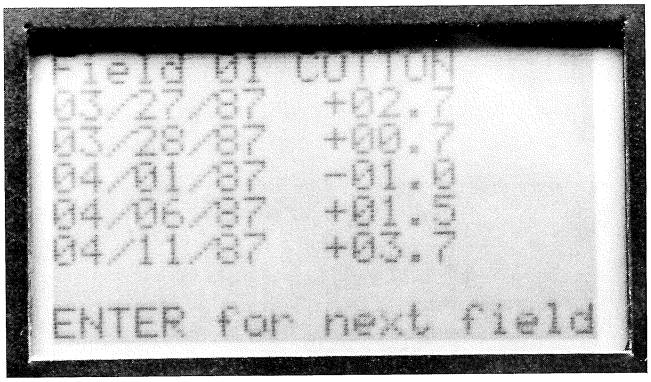
Research indicates that yield reductions may occur if the stress index is consistently above the dotted horizontal line on the **Historical Graph Screen.**

In the example above, the indexes recorded in the past 15 days are displayed, with the current date and the last sample on the far right. This was calculated using the field summary where samples were collected 4 of the past 15 days. Samples taken at less than the ideal standard of at least 65% of full sun are indicated by a hollow dot. (Such readings are possible only when the **Sun Low Error** feature is deactivated, page 14).

- If you want to sample another field, press **ENTER.**
- To list the stress index values represented in the graph, press CALC. This will display the **15-Day Historical Table** screen*

The 15 Day Historical Table

The 15 days of historical data you have just seen represented on the graph are listed in this table. Since the screen is limited in size to showing no more than 5 days of data at a time, you have to use the **UP** or **DOWN** arrow keys to move through this listing to see the full 15 days.



15 day Historical Table Screen

- To sample another field, press **ENTER.**

* Note: The R/D Consultant Model has a 200 field capacity with a one-day memory.

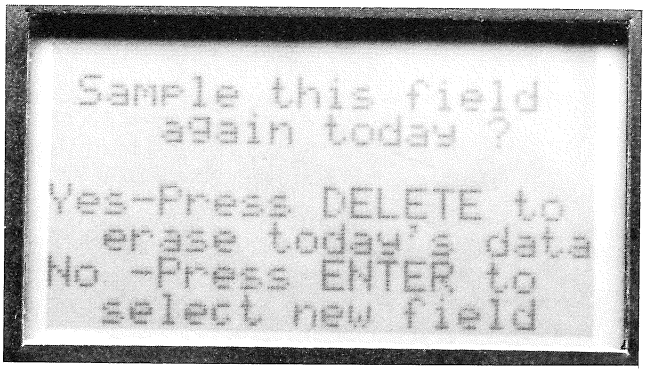
Chapter 4.

Other Monitor Program Features

Returning to the Same Field for Sampling

The Monitor prevents you from erasing information by accidentally resampling the same numbered field the same day. However, if you want to resample the same field the same day, follow this procedure:

- Select the appropriate field number at the **Field Selection** screen.
- Specify that you want to take samples by pressing **ENTER.** The following screen appears



Re-sample Field Screen.

- Follow screen instructions. The Monitor will erase only that day's information for the selected field.

Using High/Low Crop Settings

In general, all plants react to their environment in similar ways. The leaf temperature is dependent upon the plant's moisture evaporation rate (transpiration). We suggest that you use the "High" setting for plants with slow transpiration rates, such as tree crops. Use the "Low" setting for plant types that are large consumers of water.

You will find it easy to Monitor a crop throughout several irrigation cycles. You'll notice higher index readings during the driest soil conditions, and you will soon learn which index values are critical for specific crop applications.

Deactivating The Sun Low Error Feature

The "Sun" feature (sunlight intensity) of the Monitor can be deactivated, allowing you to use the other measuring capabilities of the instrument (humidity, infrared temp., air temp.) indoors or on cloudy days. To deactivate the Sun Low Error feature:

- Go to **Main Menu** screen. Press **PRINT.** This takes you to **Print Configuration** Screen.
- On the **Print Configuration** Screen, move down the right hand column (by pressing **ENTER** for each backlighted item) until you reach **Sun Low Err.**

Chapter 5.

Using a Printer with the Monitor

The Scheduler Plant Stress Monitor can be used with a printer by connecting through the serial port on the back of the microprocessor with the cable supplied. The Monitor uses a 25-pin connector, and was designed to be used with a printer able to handle an 80-column format, such as an Epson FX80 printer.

The Monitor is compatible with many such "serial" printers and also many PC-based computer systems. Consult your computer supplier on how to design the proper communications for your system. The information they need is in the table below:

SIGNAL NAME	25 PIN — D — SHELL CONNECTOR
Ground	1
Receive	2
DCD	20
DTR	8
Ground	7

The Monitor is programmed to print same-day sampling results or historical records from the past 15 days*.

*Note: The R/D Consultant model only stores and prints same-day records.

Printing Sample Results

On printouts of **Daily Sample Results,** the following items are listed for each field:

- Field number, crop, crop stage, and time of day.
- Averages for crop temperature, air temperature, relative humidity, and solar radiation.
- Adjusted stress index.
- Number of samples taken.

```
*                    FIELD DATA FOR 03/25/87

                                        AVERAGES              STRESS   SAMPLES
FIELD    CROP    STAGE   TIME    CROP     AIR    RH   SUN     INDEX     TAKEN

  01 CORN                09:35 +027.9 +030.2   20   000      +02.4        03
  02 ---- No samples taken ----
  03 ---- No samples taken ----
```

- Use the **UP** or **DOWN** arrow to change the setting. **ENABLE** activates the Monitor's automatic checking mode and keeps you from taking low light readings. Selecting **DISABLE** allows you to use the Sensor Gun under any lighting conditions.

- By pressing **ENTER** two more times you will be returned to the Main Menu Screen.

If you deactivate the "Sun" feature, the readings you get will show up on the **Historical Graph** as a hollow dot, and may not be as accurate as readings taken when the "Sun" feature is activated and readings are taken in full sunlight.

Erasing Field History

It's important to remember that information, once erased, cannot be recalled.

- To delete records, select the **PRINT** option on the **Main Menu** screen. This takes you to the **Print Configuration** screen.

- Press **ENTER.** This takes you to the **Print Mode** screen. Press **PRINT** (as if you are connecting a serial port to a printer). A screen with this message:

  "Sending data to the RS232 port, please standby"

  appears briefly, to be replaced by:

  "Do you want to erase memory?"

- If you want to erase memory, press **DEL** and follow the instructions on the screen. *This procedure will erase all records in the memory.*

- If you do not want to erase memory, press **ENTER.** You will be returned to the **Main Menu Screen.**

Historical Records

On printouts of **15-Day Historical Records,** the following items are listed for each field:

- ☐ Field number
- ☐ Date
- ☐ Stress index
- ☐ Day type (cloudy or sunny)

```
          15 DAY HISTORICAL DATA

FIELD    DATE     STRESS INDEX   DAY TYPE

  01   03/23/87       +02.3        CLOUDY
  01   03/24/87       +04.0        CLOUDY
  01   03/25/87       +02.4        CLOUDY
  02   ---- No historical data ----
  03   ---- No historical data ----
  04   ---- No historical data ----
  05   03/23/87       +02.6        CLOUDY
  06   ---- No historical data ----
```

To print sample results, turn on the Monitor and press **PRINT** on the **Main Menu** screen. The **Print Configuration Screen** appears.
The **Print Configuration Screen** is where you configure the serial port. If you are using an Epson FX80 printer, for example, the printer and the Monitor are configured as follows:

- ☐ 1200 baud
- ☐ 7 bits/character
- ☐ 2 stop bits
- ☐ No parity
- ☐ DTR protocol

- For each category, use the **UP/DOWN** keys to change specifications and press **ENTER** to save your choice (other configurations are available).

- When you complete the final category, the **Choose Printout** screen appears. To choose what type of printout you want, follow the instructions on the screen.

- The **Print Mode** screen appears and requests you to connect the hardware. The Monitor comes with a standard RS232 serial port. Connect the cable to the printer port jack (see diagram, p. 1).

- Press **PRINT** to begin sending data to your printer. Press **ENTER** to stop printing.

Chapter 6.

Care and Maintenance of Your Scheduler Plant Stress Monitor

Important! The Monitor was designed for outdoor use, but it is a complex electronic instrument and care must be exercised in its use and maintenance if you are to have trouble-free service.

Avoid Moisture And Static

Do not get moisture on the nose of the Sensor Gun. The relative humidity and air temperature sensors are housed in the forward nose compartment, and wetting can damage them. Avoid high static areas, such as power lines. Such an environment could erase Monitor memory, or damage internal programming.

Cleaning

The casing housing the microprocessor and the Gun can be wiped clean with a soft, damp cloth and a mild detergent solution. Take care not to get any moisture into the internal workings of the instrument or the Sensor Gun. If the lens in the nose of the Sensor Gun (covering the infrared thermometer) needs cleaning, use a cotton swab wetted with ethanol. Any alcohol used for this purpose must not have denaturing additives — these will leave a residue. Remove minor accumulations of dust with a soft bristle brush.

The window protecting the solar radiation sensor at the rear of the gun can be cleaned with lens paper or a camel's hair brush (available at photography or art stores). More stubborn debris can be wiped off with a slightly dampened cloth and mild detergent. Again, take care not to get any water into the Sensor Gun.

Replacing Batteries

The Monitor is powered by six C batteries. Alkaline batteries provide the longest life (estimated 20 hours in continuous use). Zinc and rechargeable nickel-cadmium batteries can be used. Zinc battery life is estimated to be 10 hours, and nickel-cadmium batteries should be recharged after 5 hours of use. The connector for the Ni-Cad battery charger is part of your printer cable. The Monitor is equipped with an internal lithium cell that powers the clock and protects stored data. This cell has a functional life of 7 years, and must be replaced at the factory.

Prolonged Storage

- **Never store the instrument in an unheated room or shed.** Freezing temperatures can damage the Monitor.
- **Remove the batteries** if you don't plan to use the Monitor for an extended period of time. This avoids possible damage from leaking corrosives.

Checking Battery Charge

To check battery condition, consult the **Main Menu** screen. Pressing **CALC** will display the battery charge. Batteries should be replaced if the reading is less than 6.7 volts. Pressing **CALC** again will return you to the **Main Menu** screen.

The Monitor will warn you when batteries are failing. A warning screen will appear when you are taking samples. Replace the batteries before doing any more sampling. There is a pouch built into the carrying case to hold spare batteries — always keep an extra set on hand in case you need them.

Resetting the Time and Date

The Monitor clock accounts for leap years. However, changes in time zones or switching to daylight savings time requires resetting the clock. Reset the clock and date by using the **Field Selection** Screen. Highlight the time or date, press **CALC,** and use the **UP** and **DOWN** arrows to make adjustments just as you would with a digital watch.

Service

WARNING: DO NOT ATTEMPT TO SERVICE THE MONITOR OR THE SENSOR GUN BY OPENING THE PROTECTIVE HOUSINGS. There are no user-servicable parts inside the Monitor or the gun. If you have a service problem you cannot solve, contact your local dealer or address your inquiries to the following:

Standard Oil Engineered Materials Co.
Sensor Technologies
PO Box 391316
6180 Cochran Road
Solon, Ohio 44139
Attn: Service Dept.

Or call (216) 349-6881

Operational Features of the Scheduler Plant Stress Monitor

- Operating specifications for the sensors for measuring crop canopy temperature and environmental conditions:

Operating Temperature	50°F
Infrared Thermometer	± 1°F
Air Temperature	± .5°F
Relative Humidity	± 5%
Solar Radiation	± 10% of full solar load

- External jack, cable, and RS 232 25-pin serial connector for connection to a PC computer or serial printer.

- Sampling range is from 1 inch to 1,000 feet with sample size from 1 to 20,000 square feet (single leaf to large canopy areas).

WARNING: This equipment generates, uses, and can radiate radio frequency energy, and if not installed and used in accordance with the instructions manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference.

Scheduler™ Plant Stress Monitor Product Registration

Fill out the Product Reservation Card at the bottom of this page, clip and return to:

Standard Oil Engineered Materials Co.
Sensor Technologies
P.O. Box 391316
6180 Cochran Road
Solon, Ohio 44139

IMPORTANT! Return of this card is important to insure this Product receives proper post-sale service.

ONE YEAR LIMITED WARRANTY

Seller warrants Scheduler to be free from defects in material and workmanship under normal use and conditions for a period of one year from date of purchase. In the event service should be necessary for any reason due to manufacturing defect or malfunction during the warranty period Seller will repair or replace at its discretion, the defective Scheduler at no charge (except for a small charge for handling, packing, return postage, and insurance), upon delivery of the Scheduler to Standard Oil Engineered Materials Co., 4440 Warrensville Rd., Cleveland, OH 44128, along with a copy of proof of purchase date. This warranty is valid only in the United States of America and does not extend to owners of this product subsequent to the original purchaser. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES, EXPRESS, IMPLIED OR STATUTORY AND DOES NOT INCLUDE ANY WARRANTY OF MERCHANTABILITY OR OF FITNESS FOR A PARTICULAR PURPOSE. UNDER NO CIRCUMSTANCES SHALL SELLER BE LIABLE FOR ANY LOSS OR DAMAGE, DIRECT, INCIDENTAL OR CONSEQUENTIAL SUCH AS BUT NOT LIMITED TO, CROP DAMAGE, ARISING OUT OF THE USE OF, OR INABILITY TO USE THE SCHEDULER THIS WARRANTY GIVES YOU SPECIFIC LEGAL RIGHTS AND YOU MAY ALSO HAVE OTHER RIGHTS WHICH MAY VARY FROM STATE TO STATE.

Product Registration Card

Owner _____

Street _____

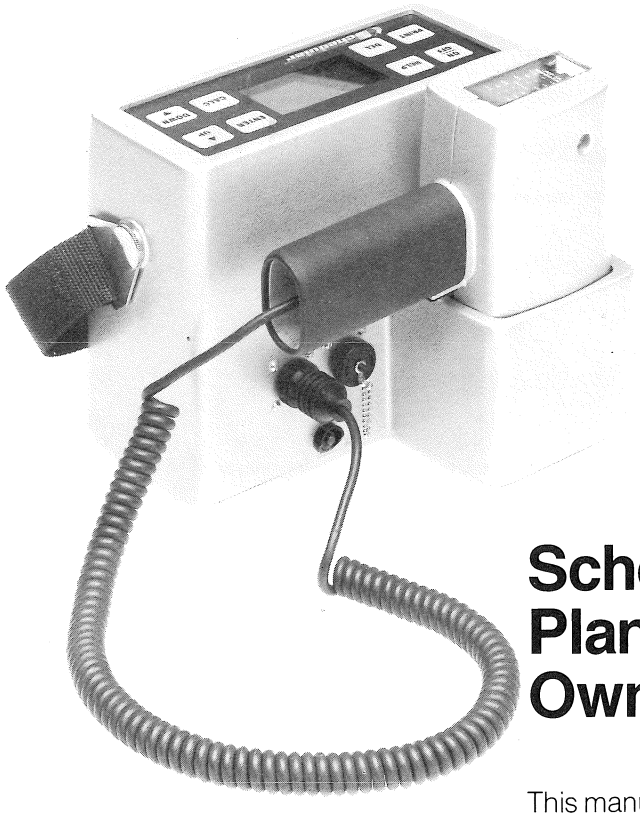
City/State _____

Zip Code _____

Dealer _____

Date Purchased _____

Serial No. _____



Scheduler™ Plant Stress Monitor Owner's Manual

This manual helps make the setup, day-to-day operation, and maintenance of your Scheduler Plant Stress Monitor quick and easy. The manual takes you step-by-step through each procedure, with photographs and illustrations to guide you.

First, read the section of the manual titled *Meet The Scheduler Plant Stress Monitor.* You'll find practical tips on how to get the most out of your Monitor.

IMPORTANT! This sign is used throughout the manual to indicate information critical to the successful operation of the Monitor.

Manual Outline

- ☐ **Meet the Scheduler Plant Stress Monitor.**
- ☐ **Chapter 1 — What the Scheduler Plant Stress Monitor Can Do.**
- ☐ **Chapter 2 — What the Plant Stress Index Is and How It Helps You Achieve Healthier Crops.**
- ☐ **Chapter 3 — Using Your Monitor and Analyzing Your Results.**
- ☐ **Chapter 4 — Other Monitor Features.**
- ☐ **Chapter 5 — Using a Printer With Your Monitor.**
- ☐ **Chapter 6 — Care and Maintenance of Your Monitor.**

Standard Oil Engineered Materials Company

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Meet the Scheduler Plant Stress Monitor

The Scheduler Plant Stress Monitor combines the latest in agriculture technology and computer know-how into a small, portable unit that takes the guesswork out of irrigation.

Point the Sensor Gun at a field of corn, sorghum, or a number of other agricultural or vegetable crops. Then pull the trigger. The Monitor automatically measures crop temperature, air temperature, sunlight level, and humidity. Then the 64K microprocessor takes over, analyzing the data to give you an instant report on the state of your crop — it tells you if it's too wet, too dry, or within acceptable limits.

When used properly, the Monitor detects plant stress brought about by too much water or too little water long before it is apparent to the eye and in plenty of time to take corrective action. The result is healthier crops, often a savings in both water and fuel, and a dollar savings for you.

Scheduler Plant Stress Monitor Features

- ☐ Portable, battery operated. Total weight 8 lbs.
- ☐ Sensor package for measuring crop environment and crop canopy temperature. Sensor Gun bar graph for helping locate problem areas (hot spots).
- ☐ 64K microprocessor, control panel with soft-touch controls, LCD display screen.
- ☐ External outlet for connecting printer or other PC-based equipment. Connecting cable.
- ☐ Soft Cordura carrying case with shoulder strap.

R/D Consultant Model

The Scheduler Plant Stress Monitor comes in two models — the Production Model and the **R/D Consultant Model.** The **R/D Consultant Model** is a special edition designed for crop consultants and agriculture research applications. Special features are:

- One-day memory for 200 plot locations, with rapid access to plot information.
- Print feature downloads location averages for all measurements and calculated values.
- Displays Vapor Pressure Deficit (VPD) and the standard deviation of crop temperature in addition to the regular measurements programmed into the Monitor.

What the Scheduler Plant Stress Monitor Can Do

The Scheduler Plant Stress Monitor is a management tool that allows the best crop manager to become even better:

- The Monitor has a capacity of tracking up to 30 separate crop fields, and providing up to 100 samples per field.*
- Its microprocessing capability lets you store measurements in memory for up to two weeks.*
- A single measurement can view over 500 times the sample area of a single tensiometer or soil probe reading.
- Multiple observations are easy and improve sampling accuracy.
- You get on-the-spot results of your sampling.

*Note: The **R/D Consultant Model** will Monitor up to 200 fields, with a one-day memory.

Soil Probes

If you use the Monitor in conjunction with soil probes or other soil moisture sensing devices, it will provide even more insights into soil moisture levels, reserves, and irrigation timing.

Spotting Insect Damage and Crop Disease

The Monitor is useful in spotting crop diseases and insect problems. How? The Monitor reacts to any problem that reduces a plant's transpiration rate. This reaction is *usually* caused by the lack of soil moisture, but if that can be ruled out as a possible cause, then insect damage or crop disease can be the culprit. These areas usually appear as "hot spots" (easily identified with the Sensor Gun), that can later spread throughout a field.

Non-Plant Uses

The Monitor can be useful in ways other than plant monitoring. It really depends on your operation — and your imagination. For instance, it can be used to measure surface temperature of walls, animals, or grain. If you need to know surface temperatures, air temperatures, or humidity of just about any environment, the Monitor will tell you.

The Scheduler Plant Stress Monitor must only be used in air temperatures above 50° F (10° C). The sensors have been designed to operate between 50°F and 140°F. The unit should be operated within these limits for maximum efficiency.

What a Plant Stress Index Is and How It Helps You Have Healthier Crops

Changing conditions can affect plants. Years of extensive agricultural research have been devoted to the monitoring of plant stress. The plant stress index calculated by the Scheduler Plant Stress Monitor is a product of that research.

Plants, like humans, react differently under different environmental circumstances. With a plant, the canopy temperature is a key indicator of how it's reacting to the local environment. When this surface temperature is compared to air temperature, relative humidity, and sunlight level, you can determine a plant's stress status. This is what the Monitor measures and analyzes.

In the field, the Monitor compares the temperature of a plant to its total environment, measuring and analyzing:

- Relative humidity
- Air temperature
- Plant temperature
- Sunlight intensity.

These measurements are used by the microprocessor to calculate the plant stress index. The result is a quick, accurate measurement of crop stress status. Knowing this helps you anticipate irrigation needs and analyze irrigation or rainfall effectiveness.

Within a few hours of irrigation or rainfall you can expect a reduction in the plant stress index. However, in some cases, the full reduction could take a day or longer, especially if the plant was severely stressed. This may be caused by slow water penetration or delays in regrowth of damaged roots.

In the case of severe overwatering (soil saturation), an increase of the plant stress index can occur. This is caused by lack of oxygen to the roots, which inhibits the ability of the plant to absorb water from the soil, resulting in an increase in the plant stress index.

What Does the Plant Stress Index Mean?

As calculated by the Monitor, index readings of zero (0) or below indicate a plant is extremely well watered. A measurement in the 0 — 2 range indicates that a plant is operating at top efficiency. Research indicates that, for most plant types, stress levels above 2 can cause plant performance to suffer.

Remember, good judgment is always the responsibility of the crop manager.

Custom Crop Programming

Plant types vary widely in their reaction to moisture, and one formula does not apply to all. The Monitor can be programmed to provide the stress index for many crops. The basic programmed package supplied with each Monitor determines the crop stress index for 5 specific crops. Current crops offered include:

- Corn
- Wheat
- Tomatoes
- Soybeans
- Cucumbers
- Alfalfa
- Barley
- Potatoes
- Cotton
- Sugar beets
- Grapes
- Grain sorghum

In addition to the basic package of five pre-programmed crops, the Monitor accommodates two general purpose crop settings (low and high). These can be used for tracking specific crops that might not be covered in the pre-programmed package. It is up to the user to decide what crop he wants to track, and to select the setting option accordingly (see **Using The High/ Low Crop Settings** on page 14).

Chapter 3.

Using Your Scheduler Plant Stress Monitor and Analyzing Your Results

Unpacking and Setup

The Scheduler Plant Stress Monitor includes the following equipment:

- 64K microprocessor, contained in a durable housing with molded holster (for the Sensor Gun). Outlet port and cable for attachment to printer or compatible computer. Adjustable strap.
- Infrared Sensor Gun with attached cable.
- Soft-side carrying case.
- Battery pouch.

Assembly

The Monitor comes fully assembled and ready to take readings. There is a cover over the printer port to protect it from dirt.

Using the Scheduler Plant Stress Monitor Sensor Gun

IMPORTANT! Read this entire section carefully. Proper use of the Sensor Gun is critical to taking accurate samples.

The Sensor Gun is the sampling tool of the Monitor. Point the gun at the target plant or field, squeeze the trigger, and you get all the information necessary for the Monitor to plot the stess index.

How To Get A Good Reading

Readings must be taken looking at the sunlit side of the plant (sun at the viewer's back). **Proper use of the Monitor requires that the gun "sees" only vegetation. Bare soil, open sky, water, buildings, etc. in the gun's viewing area will result in an inaccurate reading.**

Sampling Guidelines

You want your sample to reflect average conditions. Therefore, follow these guidelines for best results:

1. The Monitor must be used during the peak sunlit hours of the day, when plant stress is most likely to occur. The recommended time to take samples in the **summer** is between 11 am and 4 pm. The time to take samples during the **winter** growing season is between 1 pm to 3 pm.

2. The plant leaf surface must be dry.

3. **The Monitor operates best under full sunlight conditions. Therefore, for best results, the area to be sampled should be in direct sunlight.**

Unless you have purposely deactivated the sunlight sensing feature (page 14), the instrument will tell you when the sunlight level is too low for a valid reading. If a cloud's shadow should pass over the area being sampled, you must wait 30 seconds after the sun reappears for the area to warm up again before a sample is taken.

4. Use the Monitor in the field. **Don't take readings from inside a vehicle or building.** The sunlight sensor on the top rear surface of the gun must be exposed to the sun when taking readings. It will not operate properly if shaded.

5. Make sure only green, sunlit vegetation is "seen" by the gun — no bare soil or horizon.

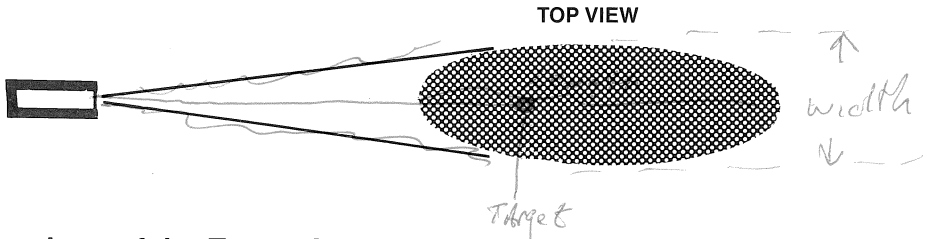
6. Air temperature extremes are likely on road surfaces, so avoid taking samples while standing on roadways.

Sampling Techniques

You can take samples one at a time by pointing the Sensor Gun at a specific area and pulling and releasing the trigger or you can "scan" an area by holding the trigger down and slowly sweeping the Sensor Gun from one side to the other. Using this method, the Gun will take readings every ¼ second, supplying a panorama of crop conditions in a broad area.

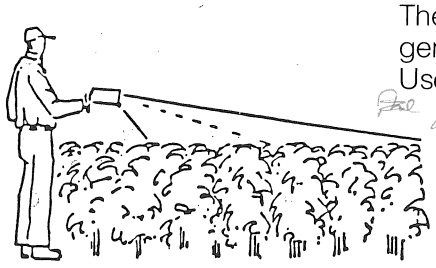
How the Sensor Gun Works

With the Sensor Gun, you simply point and "shoot". The gun "sees" a oval-shaped area (below), similar in shape to the area lighted by a flashlight. The size of this oval-shaped viewing area is controlled by how high you hold the gun above the target area, and also by how far away the target area is from the gun.



Dimensions of the Zone "Seen" by the Sensor Gun

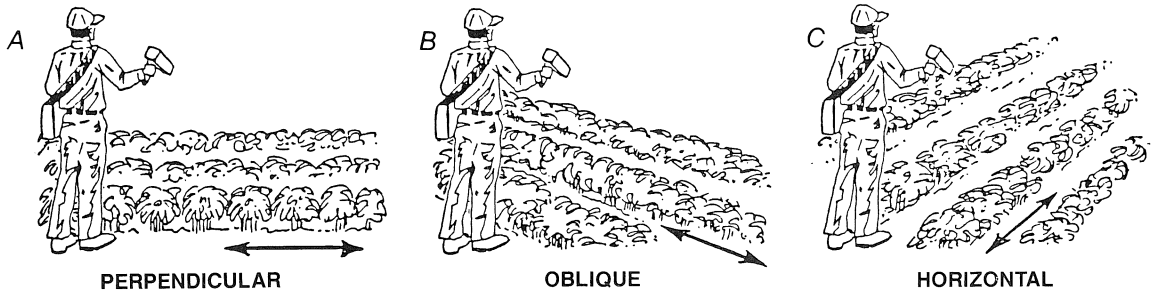
HEIGHT ABOVE CANOPY (FT.)	DISTANCE TO TARGET (FT.)	OVAL LENGTH (FT.)	MAX. OVAL WIDTH (FT.)	AREA VIEWED (SQ. FT.)
3	40	48	2	120
5	120	680	8	8200



The technique for using the Sensor Gun will change as a crop matures. As a general guideline, the gun should never be closer than 3 feet from the soil. Use the following guidelines when aiming at the plant target:

- 25 feet should be the limit to your aim when the Sensor Gun is positioned approximately 1 foot above the crop canopy.
- 75 feet is the limit at 3 feet above the canopy.
- 120 feet is the limit at 5 feet above the canopy.

There are several ways to measure a row crop, depending on the viewing angle of the Sensor Gun and the position of the sun.



(A) Across the row(s). perpendicular to row length.

(B) Across several rows, at some oblique angle.

(C) Down the length of one row.

How Many Samples Should I Take?

The Monitor can take many samples in seconds. Generally, the larger the area being sampled, the more readings are required. For example:

- For a field of 1 to 40 acres, 15 or 20 samples should be sufficient.
- A large field of up to 160 acres can require 20-40 samples.

Step-by-Step Operation Guidelines

Control Panel Key Functions

Take a minute to learn the key functions of the Monitor control panel.

Monitor control panel.

ON/OFF

Pressing this key once powers up your Monitor. You'll hear a beep when you press the button — the Monitor will beep every time you press a key. Pressing the **ON/OFF** button again will turn off the Monitor.

The Monitor is programmed to turn itself off if 10 minutes pass without a key being pressed. This feature does not erase information that has been recorded before shut-off.

HELP

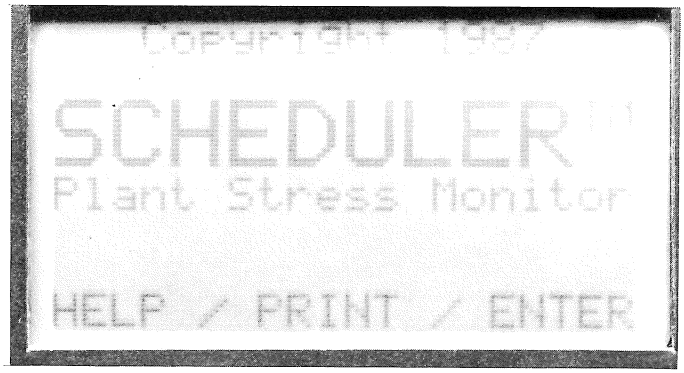
If the word **HELP** appears on the bottom of a screen, or the screen says **"Help screen available",** pressing the **HELP** key will get you step-by-step guidance and additional information.

UP/DOWN Arrows	The **UP/DOWN** arrows are used to select field number, crop choice, or adjust time and date on the screen (similar to adjusting the features of a digital watch).
ENTER	Enter field location figures, dates and times, and sample readings into memory with the **ENTER** key. The **ENTER** key also moves you through the program.
PRINT	The **PRINT** key sends information to another computer or a printer (a printer is not included in the Monitor package).
DEL (Delete)	The **DEL(Delete)** key cancels your previous selection or sample.
CALC	The **CALC** key summarizes sample data or summons historical records and graphs.

Operating The ~~Frogr~~ Scheduler

Always remove the Monitor from the fabric carrying case when you are ready to use it, and always carry the Sensor Gun in your hand while sampling. Don't return the gun to the molded holster until you move on to another field. This avoids delays for temperature adjustments.

- Press the **ON/OFF** key.* The **Main Menu** screen appears.



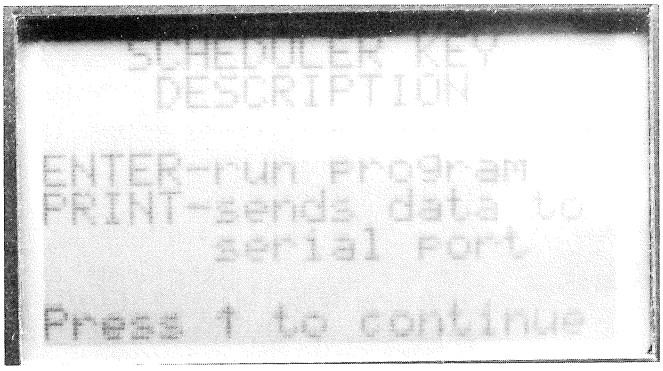
Main Menu Screen.

* Note: The Monitor gives off a series of tones (beeps) that indicate specific functions:

- One beep shows that a key has been pressed.
- •• Two beeps means that the sensors are powering up.
- ••• Three beeps indicate that a sample reading is being rejected (check the display screen for instructions).

HELP Function

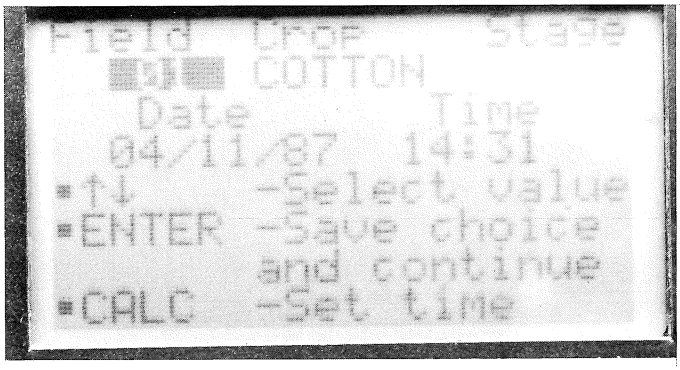
- Try the **HELP** key. By pressing **HELP,** you get the screen listing key functions for the program. To exit from **HELP,** press **HELP** again . An example of a **HELP** screen follows:



Sample Help Screen.

Field Selection Screen

- Press **ENTER** to begin. A highlighted image shows which item on the screen **(FIELD, CROP)** is ready to be entered.



Field Selection Screen

- Assign a **field identification number** to the area or field you wish to sample (from 1 to 30*). Use the **UP** or **DOWN** arrows to "count" to the number you want. This is the reference number you use when you return to that same field for additional samples on another day.
- Press **ENTER.**
- Pick your **CROP.** If you want a crop other than the one shown (**COTTON** in the screen above), use the **UP/DOWN** arrow keys to move through the available selections. ~~Where it applies, crop stage (for example, 01 for pre-head, 02 for post-head wheat) is listed next to the crop.~~ Any crop may be assigned to any field. This crop will be assigned to this field until you change it.
- Press **ENTER.**

The Monitor files the crop and field number selected, along with any readings you take in that field. Later, when you return to that same field for additional sampling, you punch up that field number on the display and then take your samples*. This is how you construct your ongoing profile of plant conditions for that location. Select

Changing An Entry

240

* Note: The **R/D Consultant Model,** has a capacity of 200 fields. To find a field number quickly without "scrolling" through the entire numbered list, follow these instructions:

- On the **Field Selection Screen,** the three-digit number is shown as **000** with the left zero (hundreds) backlighted. You use the **UP** arrow to set the number you want. Press **ENTER.**
- The middle zero (tens) and the right zero (ones) are backlighted in turn . Follow the same procedure as with the first number.

Changing an Entry

If you have made a mistake or want to change a selection, Press **DEL.** This moves you back one step and lets you try again. A **HELP** screen is available to guide you.

Clock and Calendar

The monitor's internal clock automatically tracks date and time. The date is entered as month/day/year, and the time as hours:minutes in marine time (3:25 pm, for example, is shown as 15:25). You can adjust the clock if necessary (see page 18).

Taking A Sample

After you have entered your field number and made your crop selection, a screen will inform you:

"Press **ENTER** to begin sampling. Press **CALC** to review field history." (for more about reviewing a field history, refer to **"Reviewing Records"** on page 12).

- Take the Sensor Gun out of its holster, and press **ENTER** to activate the sensor package. You get the message, **"SENSORS POWERING UP",** and a clock appears on the screen and counts down 94 seconds. Two beeps will tell you when the Sensor Gun is ready to take samples. The **"Sample Taking"** screen appears.*

Sample Taking Screen.

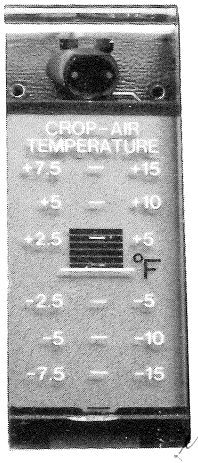
* Note: The sensors on the Sensor Gun are very sensitive to temperature variations, and can heat up when the gun is in the holster. This can result in an inaccurate reading when the gun is first taken out of the holster. An automatic delay is built into the system to allow the sensors to adjust themselves to the field environment (the 94 second delay). Therefore, sampling will go quicker if you carry the gun in your hand when you are moving from place to place in a field to take your samples.

Detecting Hot Spots

The Bar Graph on the back of the Sensor Gun was designed to quickly identify temperature variations (hot spots). **The Bar Graph only operates when the trigger is not being used.**

Use the Bar Graph on the Gun to "scan" the field and identify temperature variations and problem areas before taking any samples.

For many crops, leaf temperatures for healthy, transpiring plants are equal



to or lower than the surrounding air temperature. The **air/temp.** line on the Bar Graph represents the surrounding air temperature. The difference between that air temperature and the crop canopy temperature is indicated by the **column of bars** on the graph. In the illustration on the left, for example, the crop canopy temperature is 6° Fahrenheit higher than the air temperature.

For most readings, the difference between crop canopy and air temperatures should be within 10°F. When the difference is greater than plus or minus 15°F, it is possible that you are using the gun incorrectly. If your aim is off the target, and the gun "sees" soil, artificially high readings are the result. If you aim too high and the gun "sees" the sky, then you can get an artificially low reading.

Note: As indicated on the Bar Graph, temperature readings appear in degrees Fahrenheit (°F) on the right, and Centigrade (°C) on the left.

Taking A Reading

Aim the Sensor Gun at the target and record your reading by pressing and releasing the trigger. You'll hear a beep as the Monitor records a sample. Multiple samples can be recorded by holding the trigger down and "scanning" the target. Using this method, the Monitor will beep again and again as it records a sample each ¼ second until you release the trigger. The Monitor will record up to 100 such samples per field.

The message **CALCULATING** appears on the screen, and there is a slight delay while the Monitor records the information gathered. The length of the delay depends on the number of samples taken in one sample sequence. Wait until the **CALCULATING** message disappears before proceeding.

Sample Averages

The data that now appear on the screen reflect your last sample. To get the average of all samples, press **CALC.** To enter your information and proceed to the next field, press **ENTER** to return to the **Field Selection** screen.

Rejected Readings

The Monitor rejects readings when the sunlight level is too low, and you'll get this message:

"Sunlight Too Low"

If this happens, press **ENTER** to return to the previous screen. You can try again to get a valid sample or wait until conditions improve (the sunlight must register at least 65% of full sun for a good sample).*

On partly cloudy days, wait until the sun is not blocked by the clouds before taking samples. When the sun shines again you must allow the crop to be in full sunlight 30 seconds before beginning to sample.

* *Note:* The solar radiation ("Sun Low Error") feature can be disabled by the user for special purpose uses of the Monitor (see page 14).

Deleting Unwanted Readings

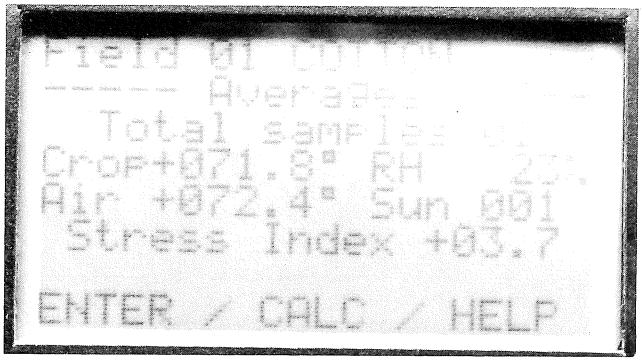
If you have taken an unwanted reading, it is important that you delete it before taking any more samples. Press **DEL** to erase your most recent sample. **You cannot delete individual readings later in the program.**

If you wait too long between samples and the Monitor automatically shuts off, you do not lose the data you have recorded. Turn on the power, and review the field history.

Your samples have been automatically averaged and calculated. If you wish to resample that same field that same day, (see **"Returning to the Same Field for Sampling,"** page 14).

Analyzing Results

- Press **CALC** when you have finished sampling a field. The **Field Summary** screen follows.



Field Summary Screen.

The stress index you see on the screen has been adjusted to be representative of the condition of the crop and field just measured. It is calculated using the averages of all the measurements recorded on the **Field Summary** screen.

At this point, you have two options:

- If you want to sample another field, press **ENTER.** This will return you to the **Field Selection** screen.

- If you want to view the graph of field summary stress indexes from the past 15 days, press **CALC.**

Reviewing Records

At any time, the Monitor allows you to review the records of the past 15 sampling days.

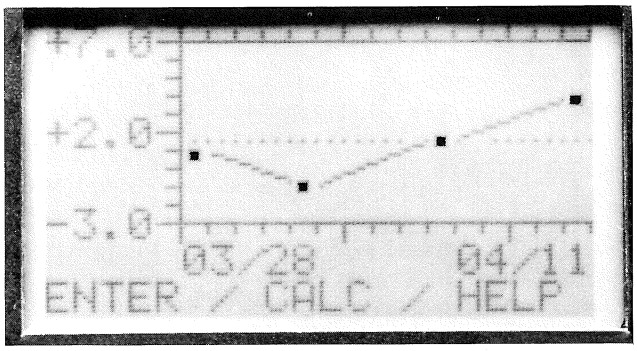
- Call up the **Field Selection** screen (page 9), and select the field number that you want to review.

- Press **ENTER** to verify the other entries on the screen, and when the screen prompts you, press **CALC** to view historical data.

If you have sampled the field that day, you will get the **Field Summary** screen. If you have not sampled the field that day, you will get the **15-day Historical Graph.**

The 15-Day Historical Graph

The Scheduler's 15-day **Historical Graph** feature allows you to monitor stress index trends and analyze irrigation effectiveness over a 15-day period. *



15-Day Historical Graph Screen.

The Dotted Stress Index Line

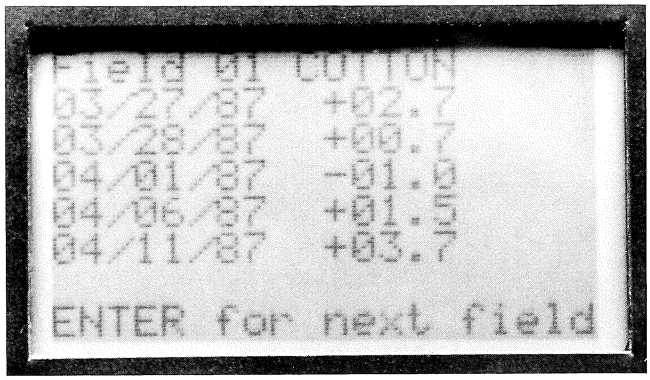
Research indicates that yield reductions may occur if the stress index is consistently above the dotted horizontal line on the **Historical Graph Screen.**

In the example above, the indexes recorded in the past 15 days are displayed, with the current date and the last sample on the far right. This was calculated using the field summary where samples were collected 4 of the past 15 days. Samples taken at less than the ideal standard of at least 65% of full sun are indicated by a hollow dot. (Such readings are possible only when the **Sun Low Error** feature is deactivated, page 14).

- If you want to sample another field, press **ENTER.**
- To list the stress index values represented in the graph, press CALC. This will display the **15-Day Historical Table** screen*

The 15 Day Historical Table

The 15 days of historical data you have just seen represented on the graph are listed in this table. Since the screen is limited in size to showing no more than 5 days of data at a time, you have to use the **UP** or **DOWN** arrow keys to move through this listing to see the full 15 days.



15 day Historical Table Screen

- To sample another field, press **ENTER.**

* Note: The R/D Consultant Model has a 200 field capacity with a one-day memory.

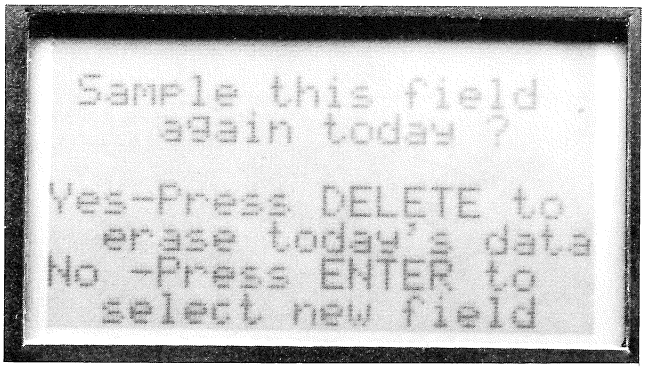
Chapter 4.

Other Monitor Program Features

Returning to the Same Field for Sampling

The Monitor prevents you from erasing information by accidentally resampling the same numbered field the same day. However, if you want to resample the same field the same day, follow this procedure:

- Select the appropriate field number at the **Field Selection** screen.
- Specify that you want to take samples by pressing **ENTER.** The following screen appears



Re-sample Field Screen.

- Follow screen instructions. The Monitor will erase only that day's information for the selected field.

Using High/Low Crop Settings

In general, all plants react to their environment in similar ways. The leaf temperature is dependent upon the plant's moisture evaporation rate (transpiration). We suggest that you use the "High" setting for plants with slow transpiration rates, such as tree crops. Use the "Low" setting for plant types that are large consumers of water.

You will find it easy to monitor a crop throughout several irrigation cycles. You'll notice higher index readings during the driest soil conditions, and you will soon learn which index values are critical for specific crop applications.

Deactivating The Sun Low Error Feature

The "Sun" feature (sunlight intensity) of the Monitor can be deactivated, allowing you to use the other measuring capabilities of the instrument (humidity, infrared temp., air temp.) indoors or on cloudy days. To deactivate the Sun Low Error feature:

- Go to **Main Menu** screen. Press **PRINT.** This takes you to **Print Configuration** Screen.
- On the **Print Configuration** Screen, move down the right hand column (by pressing **ENTER** for each backlighted item) until you reach **Sun Low Err.**

- Use the **UP** or **DOWN** arrow to change the setting. **ENABLE** activates the Monitor's automatic checking mode and keeps you from taking low light readings. Selecting **DISABLE** allows you to use the Sensor Gun under any lighting conditions.
- By pressing **ENTER** two more times you will be returned to the Main Menu Screen.

If you deactivate the "Sun" feature, the readings you get will show up on the **Historical Graph** as a hollow dot, and may not be as accurate as readings taken when the "Sun" feature is activated and readings are taken in full sunlight.

Erasing Field History

It's important to remember that information, once erased, cannot be recalled.

- To delete records, select the **PRINT** option on the **Main Menu** screen. This takes you to the **Print Configuration** screen.
- Press **ENTER.** This takes you to the **Print Mode** screen. Press **PRINT** (as if you are connecting a serial port to a printer). A screen with this message:

  "Sending data to the RS232 port, please standby"

  ~~appears briefly, to be replaced by:~~
  "Do you want to erase memory?"
- If you want to erase memory, press **DEL** and follow the instructions on the screen. *This procedure will erase all records in the memory.*
- If you do not want to erase memory, press **ENTER.** You will be returned to the **Main Menu Screen.**

Chapter 5.

Using a Printer with the Monitor

The Scheduler Plant Stress Monitor can be used with a printer by connecting through the serial port on the back of the microprocessor with the cable supplied. The Monitor uses a 25-pin connector, and was designed to be used with a printer able to handle an 80-column format, such as an Epson FX80 printer.

The Monitor is compatible with many such "serial" printers and also many PC-based computer systems. Consult your computer supplier on how to design the proper communications for your system. The information they need is in the table below:

SIGNAL NAME	25 PIN — D — SHELL CONNECTOR
Ground	1
Receive	2
DCD	20
DTR	8
Ground	7

The Monitor is programmed to print same-day sampling results or historical records from the past 15 days*.

*Note: The R/D Consultant model only stores and prints same-day records.

Printing Sample Results

On printouts of **Daily Sample Results,** the following items are listed for each field:

- Field number, crop, crop stage, and time of day.
- Averages for crop temperature, air temperature, relative humidity, and ~~solar radiation~~.
- Adjusted stress index.
- Number of samples taken.

```
*                    FIELD DATA FOR 03/25/87

                                        AVERAGES                  STRESS  SAMPLES
FIELD    CROP    STAGE   TIME    CROP     AIR    RH   SUN        INDEX    TAKEN

  01 CORN                09:35 +027.9 +030.2   20   000         +02.4       03
  02 ---- No samples taken ----
  03 ---- No samples taken ----
```

Historical Records

On printouts of **15-Day Historical Records,** the following items are listed for each field:

- ☐ Field number
- ☐ Date
- ☐ Stress index
- ☐ Day type (cloudy or sunny)

```
          15 DAY HISTORICAL DATA

FIELD    DATE     STRESS INDEX   DAY TYPE

  01   03/23/87       +02.3        CLOUDY
  01   03/24/87       +04.0        CLOUDY
  01   03/25/87       +02.4        CLOUDY
  02   --- No historical data ---
  03   --- No historical data ---
  04   --- No historical data ---
  05   03/23/87       +02.6        CLOUDY
  06   --- No historical data ---
```

To print sample results, turn on the Monitor and press **PRINT** on the **Main Menu** screen. The **Print Configuration Screen** appears.
The **Print Configuration Screen** is where you configure the serial port. If you are using an Epson FX80 printer, for example, the printer and the Monitor are configured as follows:

- ☐ 1200 baud
- ☐ 7 bits/character
- ☐ 2 stop bits
- ☐ No parity
- ☐ DTR protocol

- For each category, use the **UP/DOWN** keys to change specifications and press **ENTER** to save your choice (other configurations are available).
- When you complete the final category, the **Choose Printout** screen appears. To choose what type of printout you want, follow the instructions on the screen.
- The **Print Mode** screen appears and requests you to connect the hardware. The Monitor comes with a standard RS232 serial port. Connect the cable to the printer port jack (see diagram, p. 1).
- Press **PRINT** to begin sending data to your printer. Press **ENTER** to stop printing.

Chapter 6.

Care and Maintenance of Your Scheduler Plant Stress Monitor

Important! The Monitor was designed for outdoor use, but it is a complex electronic instrument and care must be exercised in its use and maintenance if you are to have trouble-free service.

Avoid Moisture And Static

Do not get moisture on the nose of the Sensor Gun. The relative humidity and air temperature sensors are housed in the forward nose compartment, and wetting can damage them. Avoid high static areas, such as power lines. Such an environment could erase Monitor memory, or damage internal programming.

Cleaning

The casing housing the microprocessor and the Gun can be wiped clean with a soft, damp cloth and a mild detergent solution. Take care not to get any moisture into the internal workings of the instrument or the Sensor Gun. If the lens in the nose of the Sensor Gun (covering the infrared thermometer) needs cleaning, use a cotton swab wetted with ethanol. Any alcohol used for this purpose must not have denaturing additives — these will leave a residue. Remove minor accumulations of dust with a soft bristle brush.

The window protecting the solar radiation sensor at the rear of the gun can be cleaned with lens paper or a camel's hair brush (available at photography or art stores). More stubborn debris can be wiped off with a slightly dampened cloth and mild detergent. Again, take care not to get any water into the Sensor Gun.

Replacing Batteries

The Monitor is powered by six C batteries. Alkaline batteries provide the longest life (estimated 20 hours in continuous use). Zinc and rechargeable nickel-cadmium batteries can be used. Zinc battery life is estimated to be 10 hours, and nickel-cadmium batteries should be recharged after 5 hours of use. The connector for the Ni-Cad battery charger is part of your printer cable. The Monitor is equipped with an internal lithium cell that powers the clock and protects stored data. This cell has a functional life of 7 years, and must be replaced at the factory.

Prolonged Storage

- **Never store the instrument in an unheated room or shed.** Freezing temperatures can damage the Monitor.
- **Remove the batteries** if you don't plan to use the Monitor for an extended period of time. This avoids possible damage from leaking corrosives.

Checking Battery Charge

To check battery condition, consult the **Main Menu** screen. Pressing **CALC** will display the battery charge. Batteries should be replaced if the reading is less than 6.7 volts. Pressing **CALC** again will return you to the **Main Menu** screen.

The Monitor will warn you when batteries are failing. A warning screen will appear when you are taking samples. Replace the batteries before doing any more sampling. There is a pouch built into the carrying case to hold spare batteries — always keep an extra set on hand in case you need them.

by pressing CALC from the

Resetting the Time and Date

The Monitor clock accounts for leap years. However, changes in time zones or switching to daylight savings time requires resetting the clock. Reset the clock and date ~~by using~~ the **Field Selection** Screen. Highlight the time or date, press **CALC,** and use the **UP** and **DOWN** arrows to make adjustments just as you would with a digital watch.

Service

WARNING: DO NOT ATTEMPT TO SERVICE THE MONITOR OR THE SENSOR GUN BY OPENING THE PROTECTIVE HOUSINGS. There are no user-servicable parts inside the Monitor or the gun. If you have a service problem you cannot solve, contact your local dealer or address your inquiries to the following:

Standard Oil Engineered Materials Co.
Sensor Technologies
PO Box 391316
6180 Cochran Road
Solon, Ohio 44139
Attn: Service Dept.

Or call (216) 349-6881

Chapter 7
Scheduler Hardware Features
Specifications
Advanced IRT, yet rugged (Solid State)
aspirated Air & RH
Comparison of Production & R&D features
Reprogrammable
~~Data logger feature~~
Unpacking & Set-up
re-chargeable batteries

Operational Features of the Scheduler Plant Stress Monitor

- Operating specifications for the sensors for measuring crop canopy temperature and environmental conditions:

Operating Temperature	50°F
Infrared Thermometer	± 1°F
Air Temperature	± .5°F
Relative Humidity	± 5%
Solar Radiation	± 10% of full solar load

- External jack, cable, and RS 232 25-pin serial connector for connection to a PC computer or serial printer.

- Sampling range is from 1 inch to 1,000 feet with sample size from 1 to 20,000 square feet (single leaf to large canopy areas).

WARNING: This equipment generates, uses, and can radiate radio frequency energy, and if not installed and used in accordance with the instructions manual, may cause interference to radio communications. It has been tested and found to comply with the limits for a Class A computing device pursuant to Subpart J of Part 15 of FCC Rules, which are designed to provide reasonable protection against such interference when operated in a commercial environment. Operation of this equipment in a residential area is likely to cause interference in which case the user at his own expense will be required to take whatever measures may be required to correct the interference.

SCHEDULER

PLANT STRESS MONITOR

INTRODUCTION

LEAVES

THE PRIMARY FUNCTION OF MOST LEAVES IS TO MANUFACTURE FOOD (PHOTOSYNTHESIZE). PHOTOSYNTHESIS REQUIRES THAT CARBON-DIOXIDE (CO2) ENTERS THE LEAF WHILE WATER IS EVAPORATED FROM THE LEAF (TRANSPIRATION).

RESEARCHERS HAVE KNOWN SINCE 1843 THAT MOISTURE STRESSED LEAVES ARE HOTTER THAN WELL-WATERED LEAVES ~~WHEN THE SUN IS SHINING BRIGHTLY ON THEM~~.

~~THE~~ USDA PROVED THAT IT IS PRACTICAL TO USE INFRARED THERMOMETRY TO MEASURE LEAF TEMPERATURES IN THE FIELD. USDA THEORIES HAVE BEEN TESTED AND MODIFIED IN NATION-WIDE TESTS CONDUCTED BY STANDARD OIL ENGINEERED MATERIALS.

STANDARD OIL ENGINEERED MATERIALS IS THE ONLY ORGANIZATION WHICH HAS SYSTEMATICALLY DEVELOPED AN UNDERSTANDING OF HOW TO USE INFRARED THERMOMETRY ON A DIVERSITY OF AGRICULTURAL CROPS.

UNDERSTANDING THE INDEX

WHEN PEOPLE GET SICK, THEIR TEMPERATURE RISES ABOVE 98.6. WHEN PLANTS ARE THIRSTY, OR SICK, THEY EVAPORATE WATER AT A SLOWER RATE THAN NORMAL. THE RESULT IS A PLANT THAT IS HOTTER THAN IT SHOULD BE.

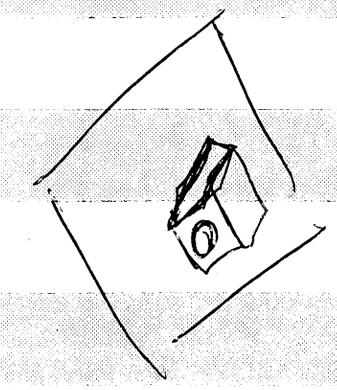
THE STRESS INDEX IS A COMPARISON BETWEEN THE ESTIMATED NORMAL LEAF TEMPERATURE AND THE MEASURED LEAF TEMPERATURE.

CLOUDS HAVE A MAJOR EFFECT ON THE INDEX BY REDUCING SUNLIGHT INTENSITY.

.WIND HAS A MINOR EFFECT ON THE INDEX. MOST EFFECTS OCCUR WHEN THE WINDSPEED IS BETWEEN 0 AND 5 MILES PER HOUR. SOME EFFECTS MAY OCCUR AT WINDSPEEDS IN EXCESS OF 20 MILES PER HOUR..

.GENERAL INTERPRETATIONS

< 0 NO STRESS



Best $L9

Clark Russell

$\left\{ \frac{(Tc - Ta)(min)}{2.88 - (2.52\,VPD)} \right\} * 10$

"you need to answer
How does the Schedule
measure this index?"
i.e. TA Tc RH + Solar etc.

0-2 MINIMAL STRESS
2-5 MODERATE STRESS
5-8 HIGH STRESS
)8 EXTREME STRESS

.
.
YIELD/QUALITY
IN GENERAL, THE COOLER A CROP STAYS (THE LOWER THE INDEX) THE HIGHER THE YIELDS AND QUALITY. THE NORMAL INDEX PATTERN IS TO CYCLE BETWEEN LOW AND MODERATE STRESS LEVELS BETWEEN IRRIGATIONS.
.
.
.
.
USING THE SCHEDULER IS EASY.
.STEP OUT OF THE TRUCK
.REMOVE THE SCHEDULER FROM ITS CASE
.TAKE THE SENSOR GUN FROM ITS HOLSTER
.TURN ON THE UNIT /WALK INTO THE FIELD
.
.
.
.
.USING THE SCHEDULER IS EASY.
. MAKE READINGS WHEN THE SUN IS SHINING BRIGHT.
. AIM ONLY AT SUNLIT GREEN VEGETATION.
. MAKE READINGS BETWEEN 11 A.M. AND 4 P.M.
. KEEP THE SENSOR GUN AT LEAST 3 FT ABOVE THE SOIL .
. . KEEP THE SCHEDULER HARDWARE NEAR AIR TEMPERATURE.
.
..
.
.
AIMING TECHNIQUES USED ON FIELD CROPS
.
.
. DOWN THE ROW
. ACROSS THE ROW
. AT INDIVIDUAL PLANTS OR LEAVES
.
.
.AIMING TECHNIQUE #1 ON TREES
.
. AIM AT THE SUNNY SIDE OF THE TREE, IF MOST OF THE LEAVES ARE SUNLIT AND THE CANOPY APPEARS SOLID.
.
.
.
AIMING TECHNIQUE #2 ON TREES
. AIM AT INDIVIDUAL LEAVES IF THEY ARE LARGE ENOUGH AND THERE ARE TOO MANY SHADOWS OR THE CANOPY IS NOT SOLID
.
.
AIMING TECHNNIQUE #2 ON TREES
. ARTIFICIALLY CREATE A SAMPLE OF SUNLIT LEAVES IF THE LEAVES ARE TOO SMALL OR THE CANOPY IS NOT SOLID.
.
.
.
COMPARING THE INDEX TO OTHER METHODS
.
.RESEARCH HAS PROVEN THAT THE SCHEDULER INDEX IS HIGHLY CORRELATED WITH :
. PRESSURE BOMB READINGS
. STOMATAL RESISTANCE
. AVAILABLE SOIL MOISTURE
. TRANSPIRATION RATE

.

.

.

.REQUIREMENTS FOR STATISTICAL ACCURACY :
24 LEAVES PER FIELD FOR THE PRESSURE BOMB (NOT PRACTICAL)
17 SAMPLES PER FIELD FOR THE SCHEDULER (PRACTICAL)

.

.

GUIDELINES

.

.

TYPICAL INDEX PATTERNS
. YOUNG PLANTS NORMALLY HAVE MODERATE STRESS LEVELS
. MATURE PLANTS NORMALLY HAVE LOW STRESS LEVELS
. SENESCING PLANTS NORMALLY HAVE MODERATE STRESS LEVELS

.

.

SOYBEANS : KEEP THE SUN AT YOUR BACK. SOYBEAN LEAVES TRACK THE SUN.

.

.

.

SORGHUM : AFTER HEADING AIM BETWEEN THE ROWS , AT INDIVIDUAL PLANTS, OR ALONG THE SUNNY SIDE OF A ROW.

.

.

WHEAT : SOIL INFLUENCES THE READINGS FOR THE FIRST 50-60 DAYS. AFTER THE CANOPY APPEARS SOLID GREEN, INDEX VALUES SHOULD BE LOW.

.

.

GRAPES : TYPICALLY USED BY SAMPLING INDIVIDUAL VINES ON THE SUNNY SIDE OF THE ROW. AVOID LEAVES WITH SHADOWS ON THEM.

.

.

TURF : CONSISTENCY IN AIMING TECHNIQUE IS IMPORTANT. COOL SEASON GRASSES ARE ABOUT 1 STRESS UNIT COOLER THAN WARM SEASON GRASSES. GREENS ARE ABOUT 1 UNIT COOLER THAN FAIRWAYS.

.

.

GENERAL TURF GUIDELINES :

<2	OPTIMAL
2-4	TRANSITIONAL
4-6	CRITICAL
>6	HIGH STRESS

.

.

.

.POTATOES
HIGHEST YIELDS AND QUALITY OBTAINED WHEN THE INDEX AVERAGES LESS THAN 1.0 AFTER 100 % GROUND COVER.
NO DAMAGE IF THE INDEX CYCLES UP TO 2.0 BEFORE IRRIGATING.
INDEX INCREASES AS THE CROP DRIES DOWN.

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.

.

RESEARCH SUPPORT

.

THESE UNIVERSITIES HAVE PROVEN THE SCHEDULER WORKS :

BRIGHAM YOUNG UNIV. UNIV. OF ARKANSAS
FRESNO STATE UNIV. OF CALIF.
MISSISSIPPI STATE UNIV. OF GEORGIA
OREGON STATE UNIV. OF IDAHO
SOUTH DAKOTA STATE UNIV. OF FLORIDA
TEXAS A&M UNIV. OF NEBRASKA
WASHINGTON STATE

.
.

THE USDA HAS PROVEN THAT THE SCHEDULER WORKS IN :
ARIZONA
CALIFORNIA
COLORADO
FLORIDA
WISCONSIN

.
.
..
.COMMERCIAL GROWERS HAVE PROVEN THE SCHEDULER WORKS IN :
ARIZONA
CALIFORNIA
FLORIDA
MISSOURI
NEBRASKA
OHIO
TENNESSEE
WASHINGTON

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.
.
.
. SCHEDULER SOFTWARE FEATURES

.
GENERAL SOFTWARE FEATURES
.EASY TO USE. NO COMPUTER EXPERIENCE NEEDED
.SEVEN USER SELECTED CROPS PER UNIT
.REAL-TIME DISPLAY OF CROP AND AIR TEMPERATURE
.BAR-GRAPH TO MAKE IT EASY TO FIND HOT-SPOTS
.
.
GENERAL SOFTWARE FEATURES
.AUTOMATIC DATA QUALITY CHECK ON SUNLIGHT LEVEL
.RAPID FIRE--TAKES A SAMPLE 4 TIMES PER SECOND
.94 SECOND WARM-UP TO INCREASE ACCURACY
.DATE,TIME,FIELD NUMBER,AND CROP STORED AUTOMATICALLY
.DOWNLOADS DATA TO EXTERNAL COMPUTER
.
.
.
.
PRODUCTION SOFTWARE
. UP TO 99 SAMPLES PER AVERAGE
. 15 DAY STORAGE OF INDEX VALUES FOR EACH OF 30 FIELDS
. IN-FIELD DISPLAY OF THE LAST 15 DAYS OF DATA
. ONE DAY STORAGE OF ALL DATA (AUTOMATIC MEMORY CLEAR)
.
.
.R&D SOFTWARE
. UP TO 999 SAMPLES PER AVERAGE
. PERMANENT STORAGE OF ALL DATA FOR EACH OF 240 FIELDS
. STANDARD DEVIATION OF CROP TEMPERATURE CALCULATED
. VAPOR PRESSURE DEFICIT STORED
. REAL-TIME DATA TRANSFER TO AN EXTERNAL COMPUTER
.

.

SUMMARY

.EXTENSIVE PRIVATE AND PUBLIC RESEARCH PROVES THE SCHEDULER WORKS

.THE SCHEDULER IS :

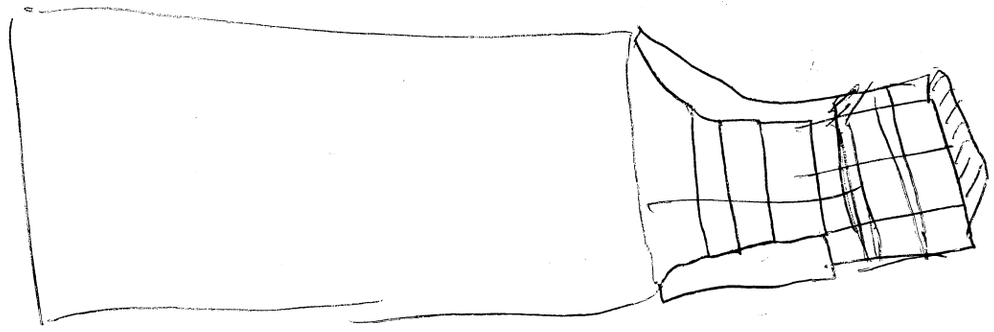
EASY TO USE

COST EFFECTIVE

MORE ACCURATE AND SENSITIVE THAT OTHER METHODS

.

Potato DATA



CWSI. Planned TRT's -- too much stress
-- needed more stress

1. Gradient exp. -- graded & quality based on soil moisture
excellent data

2.

3. Balled 4 Exp's
Avg. CWSI doesn't relate overall (season)
2 week intervals
1st 3 intervals -- either max CWSI or Avg. CWSI
↓
Stress relate to #1 potatoes
(early stress) & #2
~~Late~~ Just - end July
Late - Stress - Reduction in tonnage
Late August - not related at all

BRG
Pls call
Jeff Wade
Miss
(WSU)

2/11

Idwell
winter Oregon
& Idaho

Max. = 2.0
Goal water at 1.0 or less
never > 2.0

unclear: CWSI or Fry Color → ↓ canopy & soil temp do high, high ends develop?

Research May:

SCHEDULER ANALYSIS SOFTWARE

PRODUCTION MODELS

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SENSOR TECHNOLOGY
CARBORUNDUM
6180 COCHRAN ROAD
SOLON, OHIO 44139

216-349-6881
or
1-800-356-0458

QUICK START

> Check your hard-disk to make sure there is sufficient space to store the program by typing :

```
C:      then press  [ENTER]
DIR                 [ENTER]
```

You should have at least 180,000 bytes free.

> Your computer should have at least 256 K of RAM.

> Create a sub-directory for the programs by typing :

```
C :    then press [ENTER]
CD\               [ENTER]
MKDIR  PROD       [ENTER]
CD\PROD
COPY A:*.*   C:*.*
```

note : you do not need to use the name PROD for your sub-directory. You can use any name you like. Just substitute the name you choose for PROD wherever you see it in these instructions

> Running the program :

```
CD\PROD           [ENTER]
MENU              [ENTER]
```

CHAPTER ONE

PROGRAM SET-UP

> Start the progaram with these instructions :

```
C :       [ENTER]
CD\PROD   [ENTER]
MENU      [ENTER]
```

note, if you have stored the programs in a different sub-directory, then substitute the name of that sub-directory for PROD.

> Press "U" on the keyboard to select the Utilities menu
PRESS "T" on the keyboard to test your computer
(this test is usually done by your dealer. It determines if you have the necessary hardware to allow your computer to "talk" to the Scheduler and the proper "name" of this hardware (the proper name is either COM1 or COM2).
When you are done with this test, you will be returned to the Utilities menu.

Press "S" on the keyboard to set-up program parameters.
You will be asked to answer several questions :

- The name of the farm. The name you enter here will appear on all future reports.
- The drive the programs are stored on. Most hard drives are labeled "c" (but may have other letters. Floppy disk drives are labeled "A" or "B".
- The drive you want to store data on. Usually, the programs and data are stored on the same drive, but this is not necessary.
- Is the temperature in F or C ? Most people (in the U.S.) have their Scheduler's programmed to display temperatures in farenheit (F), but some people like to use the centigrade (C) scale.
- Is the communication port COM1 or COM2. The answer to this questions depends on the results of from the "Test" utility.
- The name of the crops in your Scheduler. This list will be used to help you in preparing reports.
- The "name" of the Scheduler field. You can assign a name (up to 28 characters long) to each Scheduler field number. The list can be modified at any time.

when you are finished with the SETUP questions, press "Q" to return to the MAIN MENU.

CHAPTER TWO

PROGRAM FEATURES

2.1 System requirements

The Scheduler analysis software was designed to run on any IBM compatible personal computer.

You may operate the program directly from the floppy disk or you may run the program from the hard-drive. Your hard disk must have at least 180,000 bytes of available storage space; one serial port;one floppy drive; 256 Kb RAM; a monochrome or color monitor (the program does not use colors); DOS 3.0 or higher (DOS 2.0 should work, but there is a potential that it won't. Try it and see).

Communications ports on some computers will occaisionally generate random characters, especially line feeds and carriage returns. This means that the file your computer stores may not be exactly like the file the Scheduler sent. The IMPORT option in the software has been designed to compensate for these occurences. If you have any difficulty importing a Scheduler file, please contact us for a solution.

The Scheduler analysis software is provided on 3.5 " and 5.25" floppy disks.

2.2 Menus

There is one MAIN menu and one UTILITIES menu. From either menu, you simply press the indicated letters or numbers to select the option you want.

2.3 Program Structure

Options	Purpose
Main Menu ---IMPORT---	--Imports data from the Scheduler and stores it in a data base
---PRINT----	--prints the Scheduler data most recently imported
---TODAY----	--makes graphs of the most recently imported Scheduler data only
---PATTERNS-	--shows you where the hot/cool and stressed/non-stressed are
---HISTG----	--makes graphs using the historical data base
---HISTP----	--prints reports using the historical data base
---UTIL-----	--utilities menu options
---Q--------	--return to DOS

Option	Purpose
Utilities Menu ----F----	edit the names of the Scheduler field numbers.
----S----	change the SET-UP options
----L----	load demonstration data.
----T----	test customers computer. This option identifies if the computer has essential hardware and the proper name (COM1 or COM2) for the serial port.
----D----	display the directory of files on the current drive
ALT-E---	exports user selected data from the historical data base to an ASCII file
ALT-I---	imports Scheduler data from an existing file and adds it to the the historical data base
ALT-R---	erases the contents of the historical data base
----E----	identifies the type and source of any hardware/software errors
----Q----	returns to main menu

CHAPTER THREE

MAIN PROGRAM

SELECTION OPTIONS

Except for the IMPORT option, all the MAIN menu options ask you to select the data which is to be used. The selection options are :

- minimum - maximum field number to use
- random selection of field numbers
- crop type

with these options, you should be able to tailor your reports to your specific needs.

3.1 IMPORT

The import option allows you to import files from the Scheduler and store the information in a permant data base.

Caution ! ! !

The Scheduler has two separate files which are labeled "TODAY's DATA" and "HISTORICAL DATA". "TODAY's" data file contains all the "raw" information :
crop temperature, air temperature, relative humidity, sunlight reading, time of day, number of samples and the name of the crop.
All this information is automatically erased at midnight! ! To preserve this information, you must import "TODAY's" data prior to midnight on the day it was collected. If you do this, there is no need to import the "HISTORICAL" file. Whenever you have questions concerning the Scheduler, or your readings, it will be very helpful to have access to the "raw" numbers. Besides, you may find them helpful or interesting, too.

The "HISTORICAL" file contained in the Scheduler contains only :
date, field number and stress index.

For up to 15 separate observations per field. The purpose of this file is to allow in-field graphs to be made on the Scheduler screen. It is not intended as a substitute for not importing your data on a daily basis. If you do not import your data on a daily basis, then it may be impossible to provide the answers to some questions which may arise.

You may import "TODAY's DATA" or "HISTORICAL" data. The program will automatically store both types of data properly.

3.2 PRINT

This option allows you to print (to the screen or a printer) the most recently imported Scheduler file exactly as it appears in your computer. This provides you with a hard-copy of the data you collected today.

Note: The "most recently imported" file is not up-dated until you import another file. This means you always have access to the data from the "last time".

3.3 TODAY

This option allows you to make graphs of the most recently imported data. You may select the data you want to graph by field number (any 1 or any combination of fields) or by crop name. For example, you may want to graph data which comes from fields 1,11,17, and 19 and exclude all the rest. Or you may want to graph only alfalfa data. If you want to graph the data from fields 1-9 (or any other range of fields), you can do that too.

You may choose from two horizontal axis options:

- time of day
- field number

You may select from 6 vertical axis options:

- crop temperature
- air temperature
- relative humidity
- sunlight reading
- stress index
- crop-air temperature difference

3.4 PATTERNS

The pattern report takes a little getting used to. After selecting which data to use, you will see a lot of little boxes. The boxes represent a single field. They will look something like this :

```
1-5   ****   *****   *****   *****   *****
```

These five boxes represent (from left to right) fields 1,2,3,4 and 5. Again :

```
6-10  ****   *****   *****   *****   *****
```

These boxes represent fields 6,7,8,9, and 10.

If you see a ****, it means that there was no data collected on that field or that you did not select that field for this particular report.

If you a number in place of the ****, then it means that data was collected on this field today and that you selected that field for this report.

USING THE PATTERN REPORT

The pattern report is very powerful once you get used to it.

You will notice that two patterns appear. Let's look at the top pattern first. Suppose it looks like this :

```
1-5   ****   -1   ****  ****  ****     CROP TEMP  = 85
6-10  ****  ****  ****  ****  ****     AIR  TEMP  = 89
11-15  0    ****   0    ****  ****     REL. HUM.  = 33
16-20 ****  ****  ****  ****  ****     SUNLIGHT   = 92
21-25 ****   1    ****  ****   6       INDEX      = 2.2
26-30 ****  ****  ****  ****  ****
```

This report means that you selected the data from 5 fields to use. The average crop temperature, air temperature, relative humidity, sunlight, and index on all 5 of these fields are given to the right.

The numbers in the first report are based on crop temperatures. A "0" means that the crop temperature on that field was equal to the average crop temperature for the five fields (in this case , 85 degrees). A -1 means that the average crop temperature was 1 degree below the average temperature. For this example, field 2 is 1 degree below the average , or 84 degrees. Field 25 has a 6 in its box. This means that the crop temperature as 6 degrees above average here (or 91 degrees).

Suppose you had selected only those fields containing cotton. If all the fields have uniform temperatures, their boxes would contain on 0's, or 1's or -1's. But a field which is unusually hot, compared to the average, immediately shows up as a large positive number. Also, a field which is unusually cool will show up as a large negative number. This report quickly alerts you to unusual areas.

The second half of the PATTERNS report is identical to the first half, except that the report is based on the stress index values. This allows you to see where non-uniformities in stress occur. This report eliminate variations in the index caused by day-to-day fluctuations. Instead, regardless of the absolute value of the index, it shows you on a relative basis how stressed an area is when compared to the overall average.

3.5 HISTG

This option allows you to make plots of all the data you have imported into the Scheduler. When you select this option, you will be asked to select the data to use according to :

- . field number (or range)
- . crop name
- . starting date
- . ending date

Caution : when you add "HISTORICAL" data files from the Scheduler, there is no crop name information. This means you could have a large data base of "HISTORICAL" Scheduler files (on grapes, let's say). If you make a plot for "GRAPES", none of this information will be graphed, since the name is not stored. To graph this information, you will need to select field numbers.

The vertical axis options are the same as for the TODAY graphs :

- Crop Temperature
- Air temperature
- Relative Humidity
- Sun-light reading
- Stress Index
- Crop-Air temperature difference

If all you have imported is "HISTORICAL" data, the only vertical option which will produce a graph (with any data points) is the stress index option. Since none of the other data is stored in the "HISTORICAL" file, there is no data to plot. This should clarify why it is important to import Scheduler data every day.

The horizontal axis options are :

- . time of day
- . field number
- . date

If all you have imported is "HISTORICAL" data, there will not be any data found when you select the "time of day" option.

You can create graphs which will show you trends for 1 field, any combination of fields or any crop. Your most complete reports can be made when you import your data every day.

3.6 HISTP

This option acts the same way as the HISTG option except that a print-out is generated (on the screen or on a printer) instead of a graph. This option allows you to create a permanent hard-copy of any records you feel are important.

CHAPTER FOUR

UTILITIES MENU

4.1 "F"

This option allows you to assign/edit your own names to each Scheduler field number. You may change any name at any time (without affecting the other names) or you may erase the names and start over again. The names you put here will be shown to you at appropriate times throughout the program, so try to select names which will help you when it comes time to making out your reports.

4.2 "S"

This option allows you to reset the program parameters (see chapter one). Any permanent data you have already stored is not affected.

4.3 "L"

This loads some demonstration data. The purpose of this file is to simply demonstrate the various graphs and reports without the need to actually collect and IMPORT Scheduler data. The data has been artificially created to demonstrate the software, there is no useful crop information in it.

4.4 "T"

This is for testing your computer. Normally this test should be conducted by your dealer or by someone who is familiar with the operation of computers. The purpose of this test is to determine if the computer has at least 1 serial port (so the Scheduler can "talk" to the computer) and to identify the technical name of this port "COM1" or "COM2". This option also allows you to import a test Scheduler file to make sure the serial port works properly.

4.5 "D"

This shows you a directory listing of all files on your current drive. When you begin importing/exporting files, you may need to refer to a directory listing of file names to avoid confusion.

4.6 ALT-E

This option is used to export data from your permanent data base to an ASCII file. You will be asked to select the data to be exported according to :

- date collected
- field number (any 1 field, or any combination) or crop name

You will also be asked for the name of the external file. The name you give it must be a correct DOS name. Refer to your DOS manual for details on how to give a correct name.

Correct DOS names follow this format :

:.@

The * represents the drive you want to store this data on (A, B, C, etc.)

The * is any name (eight-letters maximum) you want to make up (almost anything will work).

The @ is any name (three letters maximum) you want to make up. Any 3 letters are o.k. The combination "DAT" is often used for data.

For example, to EXPORT data to a file called "TESTING" to the A: drive, one correct DOS name would be :

A:TESTING.DAT

4.7 ALT-I

This option allows you to import existing Scheduler data and store it in your permanent data base.

4.8 ALT-R

The purpose of this option is to allow you to erase the contents of your permanent data base. You will be given two warnings to respond to before the file is erased.

4.9 E

Occaisionally something goes wrong, but nobody knows what. Unless the error is "fatal" (the program stops working), after an error occurs, select "U" for the Utilities menu and "E". You will be given information which shows you what type of error occured and where in the program it happened. Also given will be a list of definitions to describe to you what happened. Always check this when things don't go right. Its the fast way to find out you've overlooked something (like putting a disk in the drive). It can also help us in de-bugging the program.

CHAPTER 5

TROUBLE SHOOTING

5.1 Assistance

You can phone us at 1-800-356-0458 during working hours.

Most errors can be identified using the "E" option from the Utilities menu of the program. Sofware "bugs" and most common user errors can be isolated this way.

5.2 Other Errors

SCHEDULER DOESN'T SEND DATA

You've started the IMPORT option and the computer screen says it is ready to receive data, and you've pressed all the PRINT buttons on the SCHEDULER. The Scheduler screen says "SENDING DATA" but nothing happens on the screen. This can occaisionally occur with any computer. If this happens, just turn the Scheduler off, and EXIT the program. Then re-start the program and try IMPORT again.

If this fails to make the Scheduler send its data, you could have SET-UP the program wrong. This usually happens when a customer has two serial ports (COM1 and COM2) on his computer. Try the SET-UP routine again. Try both the COM1 and COM2 settings.

THE GRAPHS THAT ARE PRINTED DON'T LOOK LIKE THE GRAPHS ON THE SCREEN.

This is not a problem with your computer, the Scheduler, or the program. The problem is with the printer. Most printers have several optional features which are not always "enabled". One of these options allows a printer to receive graphics characters from a computer. Setting these options is usually just a matter of flipping a switch somewhere. The printer manual will need to be checked. If you have questions about this one, it is best to first check with the vendor who sold you the printer.

SCHEDULER^{R} OWNER'S MANUAL SUPPLEMENT

RESEARCH AND CONSULTANT MODEL

OVERVIEW OF THE R & D
SOFTWARE FOR THE
SCHEDULER TM PLANT STRESS MONITOR

I. Turn the unit on. There are three options: HELP, PRINT, ENTER.

HELP - Provides a description of EACH key function.

PRINT - Selects the option to Print data, reconfigure the RS-232 parameters, or reset optional program features.

ENTER - Begin execution of the Main Program.

II. Key Descriptions

ENTER - Runs program, enter selected values of field, crop, date, or time.

PRINT - Selects the option to print data, reconfigure the RS-232 parameters, or reset optional program features.

UP AND DOWN ARROWS - Selects a value of field crop, date or time, or scroll to next screen when indicated.

CALC - The first push of CALC produces sample averages, after at least 1 data point is taken. The second push of CALC (after averages are computed) automatically increments the field number by 1 and re-starts the data collection screen. If CALC is pressed immediately after the machine is turned on, the battery voltage level will be shown.

HELP - Help is used to provide information at various points in the program.

III. Print Option

The Print option can only be accessed immediately after the machine is turned on. The Print options are: CALC, ENTER, PRINT.

A. CALC - Configurations Menu. Use the Up and Down Arrow keys and the ENTER key to select:

Baud Rate (50, 75, 150, 300, 600, 1200, 1800, or 2400)
Char Size (5, 6, 7 or 8)
Stop Bits (1 or 2)
Parity (none, odd, even, mark, or space)
Xon/Xoff (enable/disable) -- allows the Scheduler™ to respond to transmit/ no transmit commands from an external device. Usually Xon/Xoff is used in the Disable mode.

B. ENTER - Flags Selection. Use the up and down arrows and the ENTER key to select:

SUN LOW ERR - (Disable or Enable). When this option is enabled, the Scheduler™ rejects any samples where the indicated sun light reading is below 65%. When this option is disabled, the Scheduler™ will take readings at all times.

DATA LOGGER - When this feature is enabled, ALL the samples collected will be transmitted through the RS-232 port for external recording by another RS-232 device. The automatic 10 minute time-out feature is disabled when this feature is enabled.

DISPLAY - Select ^{o}C or ^{o}F for the indicated temperature.

PRINT - Begins transmitting the memory file to a printer or computer. The data will not transmit if a computer or printer is not hooked up. To end a print sequence when a printer or computer is not looked up, press ENTER. Note: This is the only pathway to the ERASE MEMORY option. After the Print sequence is finished or aborted, the erase memory option will appear.

IV. Main Program

Turn machine on. Press ENTER.

1. Select field number: The field number ranges from 1 to 240. Select a field number by using the Up and Down arrows and the ENTER key. The DEL (delete) key can be used to correct mistakes. Note that each position of the field number is selectable.

2. Select Crop: Your Scheduler™ is programmed with up to seven crops selected when the unit was ordered. Once selected for a given field, the crop assigned to a field will remain until you choose to change it. If a baseline has two parts, it will be indicated by a 1 or a 2.
   1 = pre-heading 2 = post-heading

3. Set Time: To reset the Date and time, press CALC and use the ENTER and Up and Down arrows.

4. Review Field History: Press CALC. This shows the last set of data taken on this field. Field data is retained in memory until you choose to erase the memory.

5. Begin Sampling: Press ENTER. If the message, "Sample this field again today?" appears, it means you must now decide whether to keep or delete the stored data for a field. This message will appear whenever a field has stored data. To avoid seeing this message when collecting data, it is necessary to clear the memory first. See the Print option for a description of how to do this.

V. Data Collection

A 94-second countdown will always apear whenever it has been more than 10 minutes since data was last taken. The sensor gun should not be in the holster during the 94 second countdown. This will assist the air temperature and humidity sensors in equilibrating.

The Data Screen

Before the first data point is taken, the crop temperature and air temperature readings are "Alive", meaning they will display the real time readings of these sensors. In this mode, the Scheduler™ can be used as a normal infrared thermometer to scan the temperature of a surface (or observe the temperature the ambient air). Note, this mode will work for 10 minutes. If no data are taken, the unit will shut itself off.

To collect data, press the trigger or the ENTER button. Data are sampled in bursts at the rate of 4 samples per second. The data screen displays the last sample in a burst. After the data are collected (maximum of 55 samples per burst up to a total of 999 samples), the message "Calculating" appears. The more samples in a burst, the longer the calculating delay.

The data screen contains the following information:

SAMPLE - The total number of samples (up to 999).

STD - The standard deviation of crop temperature (^{o}C or ^{o})F

CROP - Crop Temperature (^{o}C or ^{o}F). The temperature displayed assumes an emissivity of 1.0.

RH - Relative Humidity (%)

AIR - Air Temperature (^{o}C or ^{o}F)

SUN - Approximates the value of direct beam solar radiation in mW/cm^{2}. The Sun reading saturates at a value of 100. This reading can also be interpreted as the percent of direct beam sunlight available.

INDEX - The CWSI value, multiplied by 10, for the crop name given at the top of the screen. The baselines used and the calculation procedures used are proprietary. They are based on the IDSO CWSI style. Modifications to IDSO's procedure have been made to allow for improved response at low VPD values.

VPD - The VPD value (kPa). All values displayed are the last sample value in a burst. This holds a sample on the screen for recording by hand or for in-field analysis.

When you have collected all the samples for a given field, press CALC to see the average of all parameters collected.

At this point, you have two options.

1) Press CALC again. This automatically increments the field number. The crop will be whatever this field has been previously set to. It is not possible to change the crop using this mode. The sensor gun does not turn off; you are ready to start another sample sequence: PULL the trigger to sample; press CALC to average; press CALC to start a new field. The data averages are automatically stored. All data points sampled can be captured by attaching an external RS-232 device (such as a polycorder) and enabling the data logging provision. Although data capture is very rapid, you will note that data calculation and transmition seem slow. This is caused by the large number of calculations performed on the data.

2) Press ENTER. This returns you to the main menu. You can select any field or crop combination. The sensor gun should turn off.

VI. Operating Suggestions

1. Keep the sensor gun out of the holster at all times during use. The holster has its own microclimate.

2. Keep the sun from directly shining on the right side of the sensor gun. It is possible for sunlight to shine directly on the air sensor, producing an error.

3. Minimize the exposure of the gun to large step-changes in ambient conditions. If the gun case is more than 15^{o}F hotter or colder than the ambient, the aspiration fan may not be able to remove all the bias caused by heat transfer between the case and the sensors. The closer the gun case remains to ambient temperature, the better.

4. Do not point the sensor gun at the sun. This can damage the IR detector (it overloads the detector). Remember, the sun has an apparent temperature of 6035^{o}C (11,000^{o}F). The Scheduler^{TM} IRT detector saturates when a target is plus or minus 150^{o}C (270^{o}F) from ambient.

5. Aim the sensor gun properly. The equations for calculating your spot size are simple. Use them to make sure you are not seeing sky. NOTE: when the sky near the horizon is seen, the indicated reading will be near ambient. When the sky several degrees above the horizon is seen, the indicated IR will be very cold, depending on the degree of cloud cover and the moisture content of the air.

6. Do not get moisture in the nose of the sensor gun. Some electrical circuitry is exposed and could be damaged.

7. Clean the lens of the IRT with ethanol that does not have denaturing additives (the additives leave a residue), or use a camel's hair brush (from an art or photography store), or with a damp cloth and a mild detergent (use distilled water).

VII. Sensors

Infrared Thermometer - Operates in the 8-14 um interval with an 8 degree total FOV. Designed and manufactured by Standard Oil Engineered Materials Company This infrared thermometer is a D.C. infrared thermometer. It does not have a mechanical chopper to compensate for changes in the temperature of the detector. Compensation is achieved by, 1) software analysis of the detector and, 2) internal thermal design. The IRT has been designed to operate within specifications as long as the internal temperature of the IRT is not changing more rapidly than $1^{o}C$ per minute. This condition will not be exceeded unless the instrument is exposed to a step-change of $20^{o}C$ ($36^{o}F$) in ambient conditions. When a step-change of this magnitude occurs, a waiting period of up to 20 minutes may be required for the instrument to operate within specifications.

Air Sensor - A thermister accurate to $0.1^{o}C$. Thermal interferance from the case reduces this accuracy to $0.2^{o}C$. IRT Case temperature should be within 15^{o} of ambient to minimize thermal interferance.

Relative Humidity Sensor - Resistance change through a bulk silicon polymer. A thermosetting resin is used which provides excellent stability. The silicon polymer protects the sensing elements from direct contact with most pollutants, including dirt. This polymer, while protecting the sensor and preserving its calibration, reduces its time response. It takes 3-5 minutes for this sensor to equilibrate to large step-changes in humidity (e.g., 20% to 60%). This should pose no problem for normal field use.

Sun-light - Two photo-diodes, wired in parallel, off-set an angle of 120°. The diode outputs remain approximately constant as the solar elevation angle changes, under sunny conditions. The output of the diodes responds to changes in solar intensity caused by clouds. In the current software, the sun reading is not used in the index calculation. It is currently used as a data-quality feature. If the sun reading is below 65, readings will be automatically rejected. This feature can be disabled.

APPENDIX I

Calculating the spot size of an IRT

F_2 = (FOV/2) The IRT in the Scheduler™ has an 8° FOV at the extremes, about 6° FOV at the half power points.

H = Height of IRT above the crop canopy

D = Horizontal distance from the IRT to the target.

S = Short axis of the spot size. The distance from the target back toward the observer to the edge of the FOV.

L = Long axis of the spot size. The distance from the target away from the observer to the edge of the FOV.

K = Indicator of whether or not sky is seen. If K is positive, no sky is seen. If K is negative, sky is seen. If K is between -1 and 0, the error is probably small. For calculation purposes, if K is less than 0.001, set K=0.001, or the trigonometric functions used will blow up. If K is less than -1, the IRT readings will be seriously biased by sky temperature.

W = Maximum width of the spot size

Calculations

All trig functions are in degrees. The example given is for a FOV of 6^{o}, height of 4 ft. and target distance of 25 ft.

*F_2 = FOV/2

1) $Z = (D^2 + H^2)^{1/2} = (16 + 625)^{1/2} = 25.3$

2) $G = \text{Sin}^{-1}\left(\frac{D}{Z}\right) - F_2 = \text{Sin}^{-1}\left(\frac{25}{25.318}\right) - 3 = 77.9$

3) $C = 90 - F_2 - G = 9.09$

4) $S = \frac{Z \sin(F_2)}{\sin(G + 90)} = 6.3$ ft.

5) $K = 90 - G - 2F_2$, If $K < 0.001$, then $K = 0.001$
If $K < O$, Then "sky is seen"
If $K < -1$, Then "Do not use at this angle"
For this example, $K = 6.1$

6) $L = \frac{Z \text{ Sin } (F_2)}{\text{Sin } (K)} = 12.5$ ft.

7) T = TOTAL length of spot size = L + S
= 18.8

8) $W = 2 Z \tan (F_2) = 2.6$ ft.

9) Total area viewed = 3.14159 TW/4
= 39.2 $ft.^2$

APPENDIX II

Transmitting data to a computer.

the cable supplied with the Scheduler™ has the following configuration:

Pin #	Function
1	Case Ground
2	Receive
3	Transmit
7	Signal Ground
8	DTR Out
20	DSR In

To connect the Scheduler™ to most serial printers, the cable supplied with the Scheduler™ should be adequate.

To transmit Scheduler™ memory files or data to an IBM P.C., it is necessary to make a straight through cable with pins 6 and 8 jumpered.

To transmit Scheduler™ memory files or data to a polycorder, an adapter is needed.

Scheduler Pins	Polycorder Pins
1, 7	7
2	2
3	3
6, 8	No Connection
20	25

Software

The following commands will allow you to transfer your data to the IBM (The Scheduler™ must be attached to a COM port).

IBM

1) Mode COM X: 12, N, 8, 2 (X is the Com port number)

2) Copy COMX < File Name > Name your file

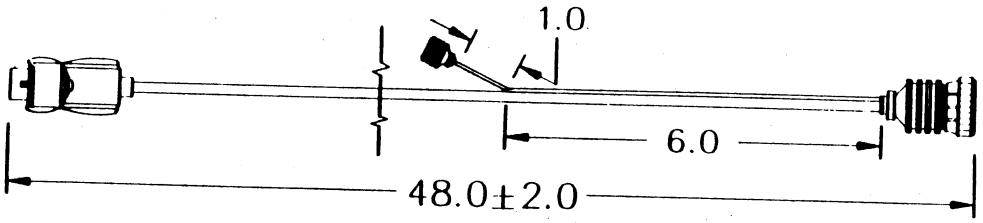
3) Configure the Scheduler™ as follows (using the PRINT option):

   Baud 1200
   Char. Size 8
   Stop Bits 2
   Parity None
   Xon/Xoff Disabled
   Sun Low Disabled or enabled

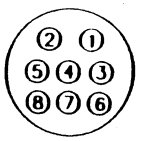
4) Execute the PRINT option.

5) All data (including headers will be transferred). A CTRL-Z is sent at the end of file to return the IBM to normal operation.

DIMS. IN INCHES



PIN CONTACTS



WIRING SCHEDULE

SIGNAL DESCRIPTION	SIGNAL NAME	8 PIN CIRC. CONN.	COLOR	MALE DB25	CABLE PORT
CASE GROUND	RS_GND	5	BLUE	1	NC
DATA INTO COMPUTER	RS_RXD ◄—	3	BRN	2	NC
DATA FROM COMPUTER	RS_TXD —►	6	GREEN	3	NC
SIGNAL GROUND	RS_GND	5	BLUE	7	NC
DTR OUT OF COMPUTER	RS_DTR —►	7	ORN	8,6	NC
RING INTO COMPUTER	RS_RI ◄—	8		NC	
CARRIER INTO COMP.	RS_CD ◄—	1	YEL	20	NC
BAT. +	BAT. +	2	RED	NC	
BAT. GND.	BAT. GND.	4	BLK	NC	

JUMPER 6&8 ON DB25

PRINTER CABLE

figure -1-

SCHEDULER^{R} PLANT STRESS MONITOR
Research and Consultant Model

1. **Measurement:** Averaging function over target area for ambient air/target temperature differential calculation. Plus ambient measurement and display of relative humidity and incoming radiation. Additionally calculation and display of Standard Deviation of target temperature, vapor pressure deficit and plant stress index.

2. **Scale Range:** -30^{o} C to 100^{o} C

3. **Operating Range:** 1 inch to infinity

4. **Target Spot Size:** 6^{o} FOV

5. **Response Time:** Screen update <2.0 seconds
   Sample frequency <0.5 seconds

6. **Accuracy:** +/- 0.5^{o} C

7. **Repeatability:** +/- 0.1^{o} C

8. **Spectral Response:** 8-14 microns

9. **Emmissivity:** .99

10. **Power Source:** 6 size C ni-cad batteries and 220v/50 cycle recharger.

11. **Warranty:** 1 year

12. **Microprocessor:** 64K -- 8 bit processor

13. **Display:** 2 1/2 x 1 1/2 inches LCD display on processor
    1 1/2 x 1 inch LCD display on sensor gun

14. **Serial Interface:** RS232 25 pin male connection
    Baud rates: 50-2400
    Character size 5-8
    Download paramters selectable

15. Softside Carry Case

16. Selectable Display in ^{o}C or ^{o}F

17. **Relative Humidity Accuracy:** +/- 5%

18. **Ambient Air Temperature:** +/- $0.5^{o}C$, resolution $0.1^{o}C$

19. **Incoming Solar Radiation:** +/- 10%

20. **Display and Memory:** 240 memory locations, automatic averaging of parameters

APPLICATIONS FOR THE SCHEDULER^{R} PLANT STRESS MONITOR

The Scheduler^{R} is being used for a wide range of research purposes.

Agronomic

- Scheduling irrigation in many crops.
- Scheduling PIX applications in cotton (effectiveness decreases with increasing stress)
- Scheduling STAM applications in rice.
- Controlling bunch-rot in grapes.
- Scheduling Round-up applications on weeds (the higher the stress, the lower the kill rate).
- Measuring soil temperatures before transplanting sensitive seedlings.
- Locating "hot spots" caused by disease, insects, compaction, plugged irrigation emitters, etc.
- Quantifying the effects of too much rain or too much irrigation. Oxygen depletion commonly causes plant stress in saturated soils.
- Estimating daily evapotranspiration values.
- Quantifying the minimum temperatures plant experience at night.
- Monitoring plant temperatures during periods of concern about frost.
- Measuring fruit temperatures in grapes and other crops.
- Measuring the temperature of vital plant parts, such as stem temperatures in kiwis.
- Controlling humidity levels in vineyards.

- Insuring no stress is experienced by potatoes, watermelons, and other crops which are highly sensitive to stress, without over-irrigating.

- Generally reducing the amounts of over-irrigation.

- Controlling leaf temperatures in greenhouses. Some plants require daily cycles in vegetation temperature for optimum response. Others require constant vegetation temperatures for best response.

- Quantifying the effect of chemical applications on plants. Herbicides, insecticides and fungicides affect plants to varying degrees.

- Quantifying the uniformity of plant behavior in the field, greenhouse or nursery.

- Quantifying the drying power of the air, to relate to disease factors.

- Estimating yield reductions due to stress.

- controlling plant responses and fruit quality by careful management of stress levels.

Non-Agronomic Uses

The Scheduler^{R} does not need to be used only for agricultural purposes. Of course, the stress index itself would be invalid, but the basic parameters could be measured anywhere for any purpose.

For example:

- Monitoring electrical transformers at night to find excessively hot ones (day-time measurements couldn't be used for this purpose).

- Locating air leaks in buildings.

- Quantifying the uniformity of the temperature of any surface.

- Quantifying the environment in any location (mountains, deserts, factories, etc.).

These are some of the research uses for the Scheduler^{R} we've found in the last six-months. We expect our list of applications to grow as users become familiar with an instrument that allows them to quantify plant behavior and as they find new uses for the Scheduler^{R} unique sensor package.

SCHEDULER BENEFIT WORKSHEET

WHAT'S IMPORTANT TO ME

Name _____

Address _____

_____

Phone _____

_____ I can use in conjunction with my soil probe.
_____ Saves on pumping cost.
_____ Allows me to minimize nutrient leaching due to over-watering.
_____ Has a finance program available to spread out my cost.
_____ Tells me directly how the plant is feeling.
_____ Can be used along with my gypsum blocks.
_____ No computer skills are needed to operate the Scheduler.
_____ Detects crop stress days before I can visibly see it.
_____ Saves on labor for field monitoring.
_____ I can avoid disease problems associated with over-irrigation.
_____ Maximize my yields in relation to the water I apply.
_____ Is helpful for any use where air temperature, humidity, or surface temperature is important.
_____ Can be used along with my weather station data.
_____ I can detect early any field condition that would cause my crop temperature to rise abnormally in relation to it's environment.
_____ I could decrease my water usage by several percent.
_____ Allows me to monitor stress trends on my key crops.
_____ Use with my computer to help me with crop record keeping.
_____ Can be used with a neutron probe.
_____ Gives me more information than I've ever had before to make irrigation decisions.
_____ Saves wear and tear on equipment.
_____ I could save at least one irrigation cycle over the course of the season.
_____ Detects under-watering as well as over-watering.
_____ Allows me to stress crops at certain stages if I desire.
_____ Monitor crop's reaction to chemical applications.
_____ Speeds up my decision making process by providing immediate information.
_____ Can be used along with my tensiometers.

Comments and Questions

_____

_____

_____

Estimated Payback Time _____

Review Date _____

SCHEDULER ADVANTAGES

- DIRECT indication of plant health.
- DETECTS stress days before it becomes visible.
- MONITORS stress trends directly on the screen or on an external computer.
- EASY to use. No computer experience required.
- SIMPLE instructions for proper use.
- MINIMIZES water application without damaging the crop.
- AVOIDS problems associated with under/over-irrigation.
- REDUCES labor costs for field monitoring.
- ALLOWS controlled stress levels to be imposed, if desired.
- RESPONDS early to any field condition that causes plant temperatures to become hotter than normal.
- VERSATILE --can be used to measure surface temperature, air temperature, humidity or sunlight wherever you feel it is important.
- FLEXIBLE--records can be kept for up to 240 separate locations.
- DOWN-LOADS directly to computer (no time is lost transferring numbers by hand).
- TREND analysis software and record keeping software is available.

The Stress Index

Irrigation has traditionally been scheduled according to factors that do not include plant measurements. Since the early 1970's, the USDA, as well as several universities have been developing a crop water stress index (CWSI). This index is based on the principle that a surface which is evaporating water is cooler (under the same ambient conditions) than a similar non-evaporating surface. Hence, the rate of water evaporation from a leaf surface modifies plant temperatures. This makes it possible to define an index which directly responds to the transpiration rate of a leaf. This index also serves as an indicator of plant stress status.

The Stress Index

The stress index in the SchedulerR is:

$$Index = 10*(Tc-Ta-Min)/(Max-Min) = 10*(1 -ET/ETp)$$

ET is the actual transpiration rate.

ETp is the potential transpiration rate.

Min is the minimum temperature a rapidly transpiring plant can achieve under a given set of environmental conditions.

Max is the temperature a maximally stressed plant can achieve under a given set of environmental conditions.

Max and min are computed from proprietary algorithms. The theoretical range of the index is 0-10 for a given crop. In practice, observed values range between -3 and +13.

In order to compute the index, it is necessary to measure measure four parameters: canopy temperature, ambient air temperature , relative humidity and solar radiation.

Sample Print-out Production Model

Daily Data

FIELD DATA FOR 04/14/88

FIELD	CROP	STAGE	TIME	AVERAGES CROP	AIR	RH	SUN	STRESS INDEX	SAMPLES TAKEN
01	WHEAT	01	15:18	+072.7	+073.5	22	000	+03.6	05
02	--- No samples taken ---								
03	ALFALFA		15:18	+072.8	+073.5	22	000	+03.1	03
04	--- No samples taken ---								

15 DAY HISTORICAL DATA

FIELD	DATE	STRESS INDEX	DAY TYPE
01	08/24/87	+00.3	CLOUDY
01	08/26/87	+00.9	CLOUDY
01	04/14/88	+03.6	CLOUDY
02	--- No historical data ---		
03	04/14/88	+03.1	CLOUDY
04	--- No historical data ---		
05	--- No historical data ---		
06	--- No historical data ---		

Sample Print-out R & D Model

FIELD DATA

FIELD	CROP NAME/STAGE	DATE	TIME	------AVERAGES------ CROP	AIR	RH	SUN	STRESS INDEX	VPD	CROP SAMPLES Std	TAKEN
001	COTTON	03/30/88	13:02	+074.5	+074.8	30	000	+03.9	+2.04	+00.01	002
002	ALFALFA	04/05/88	13:09	+077.0	+076.6	35	000	+03.7	+2.03	00.00	001
003	ALMONDS	04/13/88	11:43	+075.1	+074.7	22	000	+03.9	+2.28	00.00	003

OVERVIEW OF THE R & D SOFTWARE FOR THE SCHEDULER TM PLANT STRESS MONITOR

I. Turn the unit on. There are three options: HELP, PRINT, ENTER.

HELP - Provides a description of EACH key function.

PRINT - Selects the option to Print data, reconfigure the RS-232 parameters, or reset optional program features.

ENTER - Begin execution of the Main Program.

II. Key Descriptions

ENTER - Runs program, enter selected values of field, crop, date, or time.

PRINT - Selects the option to print data, reconfigure the RS-232 parameters, or reset optional program features.

UP AND DOWN ARROWS - Selects a value of field crop, date or time, or scroll to next screen when indicated.

CALC - The first push of CALC produces sample averages, after at least 1 data point is taken. The second push of CALC (after averages are computed) automatically increments the field number by 1 and re-starts the data collection screen. If CALC is pressed immediately after the machine is turned on, the battery voltage level will be shown.

HELP - Help is used to provide information at various points in the program.

III. Print Option

The Print option can only be accessed immediately after the machine is turned on. The Print options are: CALC, ENTER, PRINT.

A. CALC - Configurations Menu. Use the Up and Down Arrow keys and the ENTER key to select:

Baud Rate (50, 75, 150, 300, 600, 1200, 1800, or 2400)
Char Size (5, 6, 7 or 8)
Stop Bits (1 or 2)
Parity (none, odd, even, mark, or space)
Xon/Xoff (enable/disable) -- allows the Scheduler™ to respond to transmit/ no transmit commands from an external device. Usually Xon/Xoff is used in the Disable mode.

B. ENTER - Flags Selection. Use the up and down arrows and the ENTER key to select:

SUN LOW ERR - (Disable or Enable). When this option is enabled, the Scheduler™ rejects any samples where the indicated sun light reading is below 65%. When this option is disabled, the Scheduler™ will take readings at all times.

DATA LOGGER - When this feature is enabled, ALL the samples collected will be transmitted through the RS-232 port for external recording by another RS-232 device. The automatic 10 minute time-out feature is disabled when this feature is enabled.

DISPLAY - Select ^{o}C or ^{o}F for the indicated temperature.

PRINT - Begins transmitting the memory file to a printer or computer. The data will not transmit if a computer or printer is not hooked up. To end a print sequence when a printer or computer is not looked up, press ENTER. Note: This is the only pathway to the ERASE MEMORY option. After the Print sequence is finished or aborted, the erase memory option will appear.

IV. Main Program

Turn machine on. Press ENTER.

1. Select field number: The field number ranges from 1 to 240. Select a field number by using the Up and Down arrows and the ENTER key. The DEL (delete) key can be used to correct mistakes. Note that each position of the field number is selectable.

2. Select Crop: Your Scheduler™ is programmed with up to seven crops selected when the unit was ordered. Once selected for a given field, the crop assigned to a field will remain until you choose to change it. If a baseline has two parts, it will be indicated by a 1 or a 2.
   1 = pre-heading 2 = post-heading

3. Set Time: To reset the Date and time, press CALC and use the ENTER and Up and Down arrows.

4. Review Field History: Press CALC. This shows the last set of data taken on this field. Field data is retained in memory until you choose to erase the memory.

5. Begin Sampling: Press ENTER. If the message, "Sample this field again today?" appears, it means you must now decide whether to keep or delete the stored data for a field. This message will appear whenever a field has stored data. To avoid seeing this message when collecting data, it is necessary to clear the memory first. See the Print option for a description of how to do this.

V. Data Collection

A 94-second countdown will always apear whenever it has been more than 10 minutes since data was last taken. The sensor gun should not be in the holster during the 94 second countdown. This will assist the air temperature and humidity sensors in equilibrating.

The Data Screen

Before the first data point is taken, the crop temperature and air temperature readings are "Alive", meaning they will display the real time readings of these sensors. In this mode, the Scheduler™ can be used as a normal infrared thermometer to scan the temperature of a surface (or observe the temperature the ambient air). Note, this mode will work for 10 minutes. If no data are taken, the unit will shut itself off.

To collect data, press the trigger or the ENTER button. Data are sampled in bursts at the rate of 4 samples per second. The data screen displays the last sample in a burst. After the data are collected (maximum of 55 samples per burst up to a total of 999 samples), the message "Calculating" appears. The more samples in a burst, the longer the calculating delay.

The data screen contains the following information:

SAMPLE - The total number of samples (up to 999).

STD - The standard deviation of crop temperature (^{o}C or ^{o}F)

CROP - Crop Temperature (^{o}C or ^{o}F). The temperature displayed assumes an emissivity of 1.0.

RH - Relative Humidity (%)

AIR - Air Temperature (^{o}C or ^{o}F)

SUN - Approximates the value of direct beam solar radiation in mW/cm^2. The Sun reading saturates at a value of 100. This reading can also be interpreted as the percent of direct beam sunlight available.

INDEX - The CWSI value, multiplied by 10, for the crop name given at the top of the screen. The baselines used and the calculation procedures used are proprietary. They are based on the IDSO CWSI style. Modifications to IDSO's procedure have been made to allow for improved response at low VPD values.

VPD - The VPD value (kPa). All values displayed are the last sample value in a burst. This holds a sample on the screen for recording by hand or for in-field analysis.

When you have collected all the samples for a given field, press CALC to see the average of all parameters collected.

At this point, you have two options.

1) Press CALC again. This automatically increments the field number. The crop will be whatever this field has been previously set to. It is not possible to change the crop using this mode. The sensor gun does not turn off; you are ready to start another sample sequence: PULL the trigger to sample; press CALC to average; press CALC to start a new field. The data averages are automatically stored. All data points sampled can be captured by attaching an external RS-232 device (such as a polycorder) and enabling the data logging provision. Although data capture is very rapid, you will note that data calculation and transmition seem slow. This is caused by the large number of calculations performed on the data.

2) Press ENTER. This returns you to the main menu. You can select any field or crop combination. The sensor gun should turn off.

VI. Operating Suggestions

1. Keep the sensor gun out of the holster at all times during use. The holster has its own microclimate.

2. Keep the sun from directly shining on the right side of the senor gun. It is possible for sunlight to shine directly on the air sensor, producing an error.

3. Minimize the exposure of the gun to large step-changes in ambient conditions. If the gun case is more than 15^{o}F hotter or colder than the ambient, the aspiration fan may not be able to remove all the bias caused by heat transfer between the case and the sensors. The closer the gun case remains to ambient temperature, the better.

4. Do not point the sensor gun at the sun. This can damage the IR detector (it overloads the detector). Remember, the sun has an apparent temperature of 6035^{o}C (11,000^{o}F). The Scheduler^{TM} IRT detector saturates when a target is plus or minus 150^{o}C (270^{o}F) from ambient.

5. Aim the sensor gun properly. The equations for calculating your spot size are simple. Use them to make sure you are not seeing sky. NOTE: when the sky near the horizon is seen, the indicated reading will be near ambient. When the sky several degrees above the horizon is seen, the indicated IR will be very cold, depending on the degree of cloud cover and the moisture content of the air.

6. Do not get moisture in the nose of the sensor gun. Some electrical circuitry is exposed and could be damaged.

7. Clean the lens of the IRT with ethanol that does not have denaturing additives (the additives leave a residue), or use a camel's hair brush (from an art or photography store), or with a damp cloth and a mild detergent (use distilled water).

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Air Sensor - A thermister accurate to 0.1°C. Thermal interferance from the case reduces this accuracy to 0.2°C. IRT Case temperature should be within 15° of ambient to minimize thermal interferance.

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STD AND VPD
R & D INDICES

STD is the standard deviation of canopy temperature. The units are the same as canopy temperature (^{o}C or ^{o}F). The lower this number, the more uniform are the readings. Typical values of STD would be less than $2^{o}F$ or $1^{o}C$ for a canopy with dense ground cover.

VPD is the vapor pressure deficit of the air. It is an index of the drying power of the air. If VPD is divided by 6 and multiplied by 100, then the percent drying power is obtained. 100% drying power equates to air which is at a temperature of $100^{o}F$ and 10% relative humidity. It is possible for air to have a drying power greater than 100%.

FIVE IMPORTANT USES FOR THE SCHEDULER^{R} R & D PLANT STRESS MONITOR

1. Measure crop stress status. The stress index responds directly to the transpiration rate of a plant. The higher the index, the lower the transpiration rate.

2. Measure the uniformity of plant temperatures. The uniformity of plant temperatures is a valuable indicator of uniform transpiration rates. Plant temperatures will usually become non-uniform before the average stress index increases.

3. Measure the drying power of the air. The drying power of the air can be measured any time of the day or night. This index is superior to relative humidity since relative humidity provides very little information on how effectively the air can absorb moisture. For example, air at 50% RH and 90^{o}F has 2.7 times the drying power of air at 50% RH and 60^{o}F. This index is important in quantifying disease conditions and deciding when chemical applications are necessary.

4. Measure true plant tissue temperatures. Many biological studies have shown that maximum photosynthesis, transpiration and other processes are a function of tissue temperature. These studies can now be used to understand the biological behavior of leaves in the field.

5. Measure other important temperatures. In some vine crops it has been shown that vine stalk temperature and surface soil temperature are directly related to management and irrigation practices. The soil is a heat source for leaves and fruit. The temperature of this heat source can vary from as much as 20^{o}F below air temperature to 40^{o}F above air temperature, depending on the combined effects of crop type, the weather, irrigation and management practices.

TECHNICAL TRAINING SEMINAR

THE SCHEDULER PLANT STRESS MONITOR

BRONSON R. GARDNER, PH.D.

TECHNICAL TRAINING SEMINAR

PURPOSE OF THE SCHEDULER:

TO DETECT STRESS CAUSED BY :

* TOO LITTLE WATER
* TOO MUCH WATER
* INSECTS
* DISEASES
* CHEMICALS

HOW THE SCHEDULER HELPS

* SAMPLES LARGE ACREAGES FAST
* INCREASES MANPOWER EFFICIENCY
* ASSISTS IN INCREASING CROP UNIFORMITY
* INCREASES CONFIDENCE IN CROP STATUS
* DOCUMENTATION OF RESULTS

TECHNICAL TRAINING SEMINAR

THE PLANT IS THE KEY

TO SUCCESSFUL FARMING

THE IDEAL STRESS READING SHOULD BE MADE ON THE PLANT (not the soil). SOIL MOISTURE INDICATES HOW MUCH WATER REMAINS BUT DOES NOT INDICATE WHEN STESS BEGINS.

TECHNICAL TRAINING SEMINAR

SCHEDULER FEATURES

* MEASURES STRESS USING THE LATEST USDA DEVELOPED PROCEDURE (CWSI)
* ACCURATE SENSORS.
* RUGGED
* COMPUTER COMPATIBLE
* PERMANENT RECORDS
* PORTABLE
* EASY TO USE
* BATTERY OPERATED

TECHNICAL TRAINING SEMINAR

THE USDA CROP WATER STRESS INDEX

(CWSI)

CWSI IS A COMPARISON

BETWEEN "NORMAL" CROP TEMPERATURES (based on research) AND MEASURED TEMPERATURES UNDER BRIGHT SUNLIGHT CONDITIONS.

A LEAF/CANOPY THAT IS HOTTER THAN "NORMAL" IS EVAPORATING WATER AT A SLOWER RATE THAN NORMAL, I.E., IT IS STRESSED.

CWSI PHYSICS

HOT AIR SUNLIGHT INCREASED HUMIDITY EVPORATION LOW	=>	HOTTER LEAVES HIGHER INDEX VALUES

COOL AIR EVAPORATION HIGH CLOUDS/SHADE DECREASED HUMIDITY	=>	COOLER LEAVES LOWER INDEX VALUES

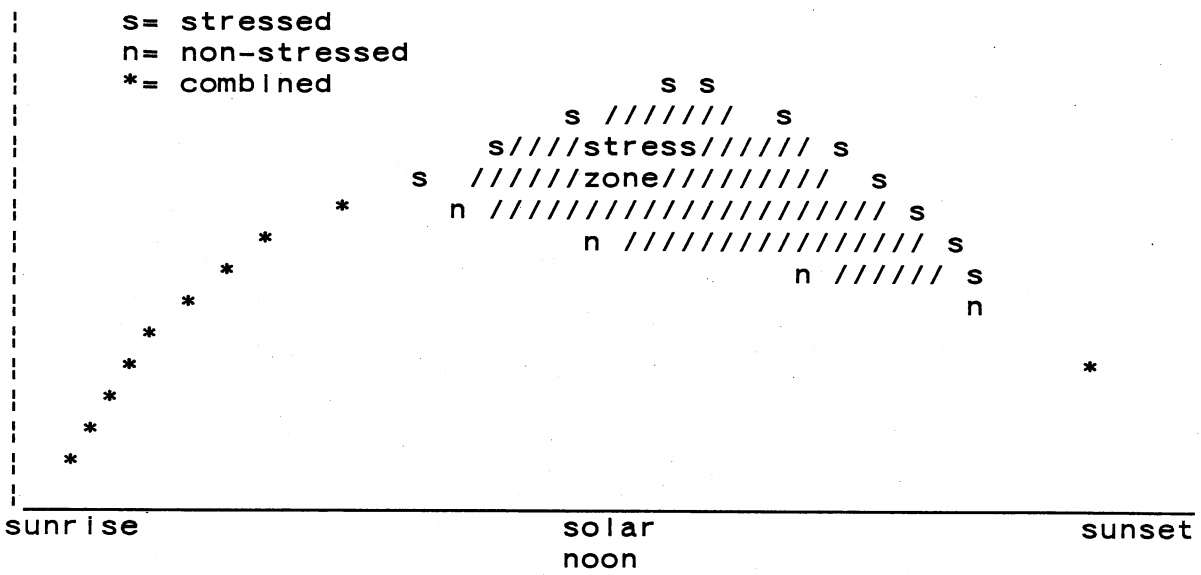
SOLAR NOON

IS YOUR KEY

REFERENCE POINT

FOR USING CWSI

ndex


s= stressed
n= non-stressed
*= combined
s s
s /////// s
s////stress////// s
s //////zone//////// s
n ////////////////////// s
n ///////////////// s
n ////// s
n
sunrise
solar
noon
sunset

ADJUSTING TO TIME OF DAY EFFECTS

- BE CONSISTENT
- SAMPLE AT SAME TIME EACH DAY
- SELECT APPROPRIATE TIME OF DAY REMEMBER THE IMPORTANCE OF SOLAR NOON

THE CWSI INDEX

$$\frac{\text{ACTUAL STRESS}}{\text{POTENTIAL STRESS}} * 10$$

THE MATH IS EASY

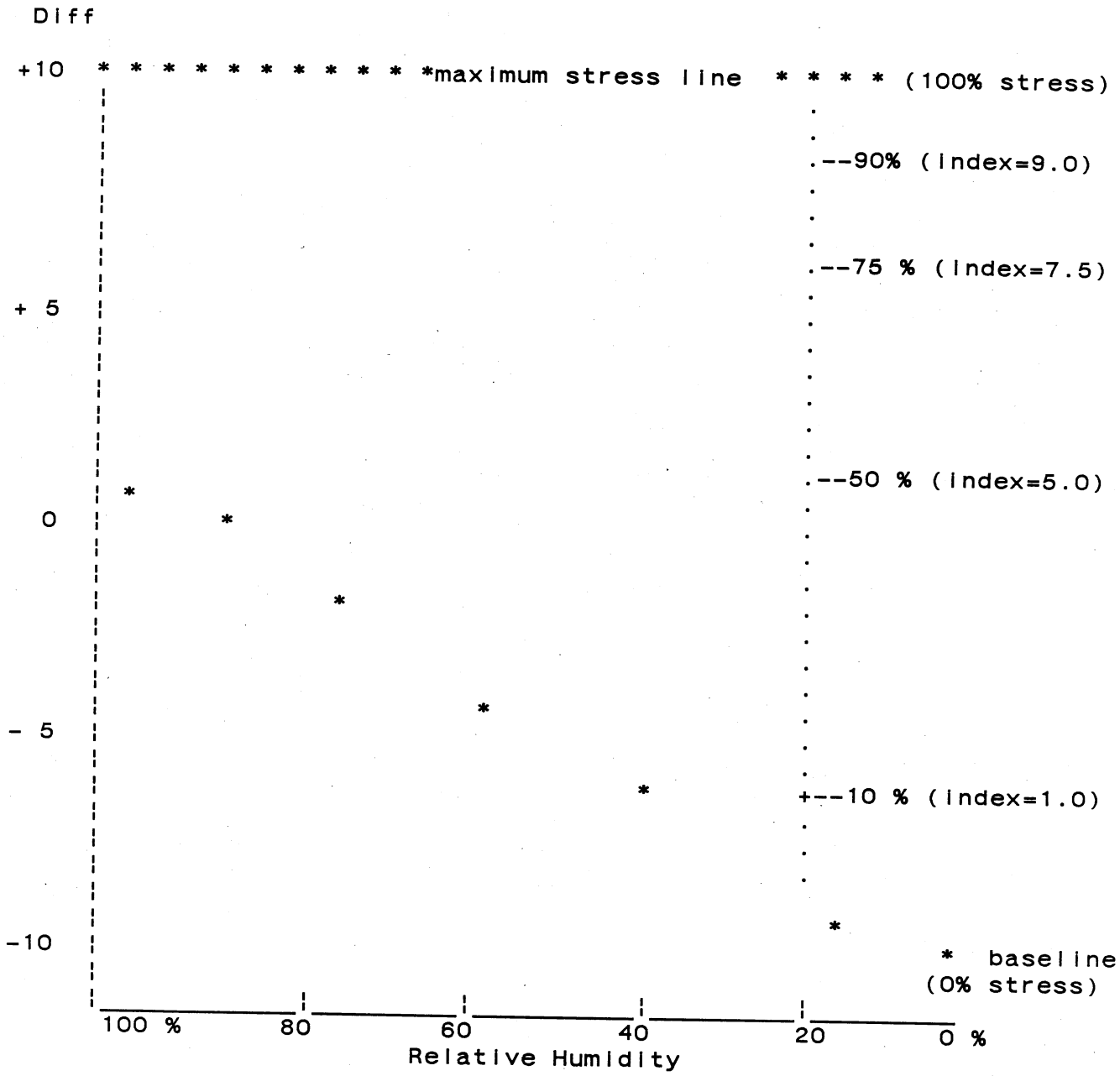
Example :

CROP TEMPERATURE	=	93° F
AIR TEMPERATURE	=	100° F
DIFFERENCE	=	- 7° F

—— NO MORE MATH NEEDED——

TECHNICAL TRAINING SEMINAR

DIFF= DIFFERENCE BETWEEN CROP & AIR TEMPERATURE (Tc – Ta)



TECHNICAL TRAINING SEMINAR

THEORY:

INDEX RANGES FROM

0 TO 10

INDEX

0	=	NO STRESS DETECTED
1	=	10% ET REDUCTION
2	=	20% ET REDUCTION
3	=	30% ET REDUCTION
4	=	40% ET REDUCTION
5	=	50% ET REDUCTION
6	=	60% ET REDUCTION
7	=	70% ET REDUCTION
8	=	80% ET REDUCTION
9	=	90% ET REDUCTION
10	=	100% ET REDUCTION

TECHNICAL TRAINING SEMINAR

REALITY:

INDEX CAN BE LESS THAN 0

OR GREATER THAN 10

WHY CWSI

CAN BE LESS THAN 0

- NORMAL BEHAVIOR (within limits)
- WET CROP
- CLOUDS
- WRONG TIME OF DAY
- AIMING TECHNIQUE (SKY SEEN)
- SHADE
- COOL AIR

TECHNICAL TRAINING SEMINAR

WHY CWSI

CAN BE GREATER THAN 10

- SEVERE STRESS
- SOIL TEMPERATURE INFLUENCE

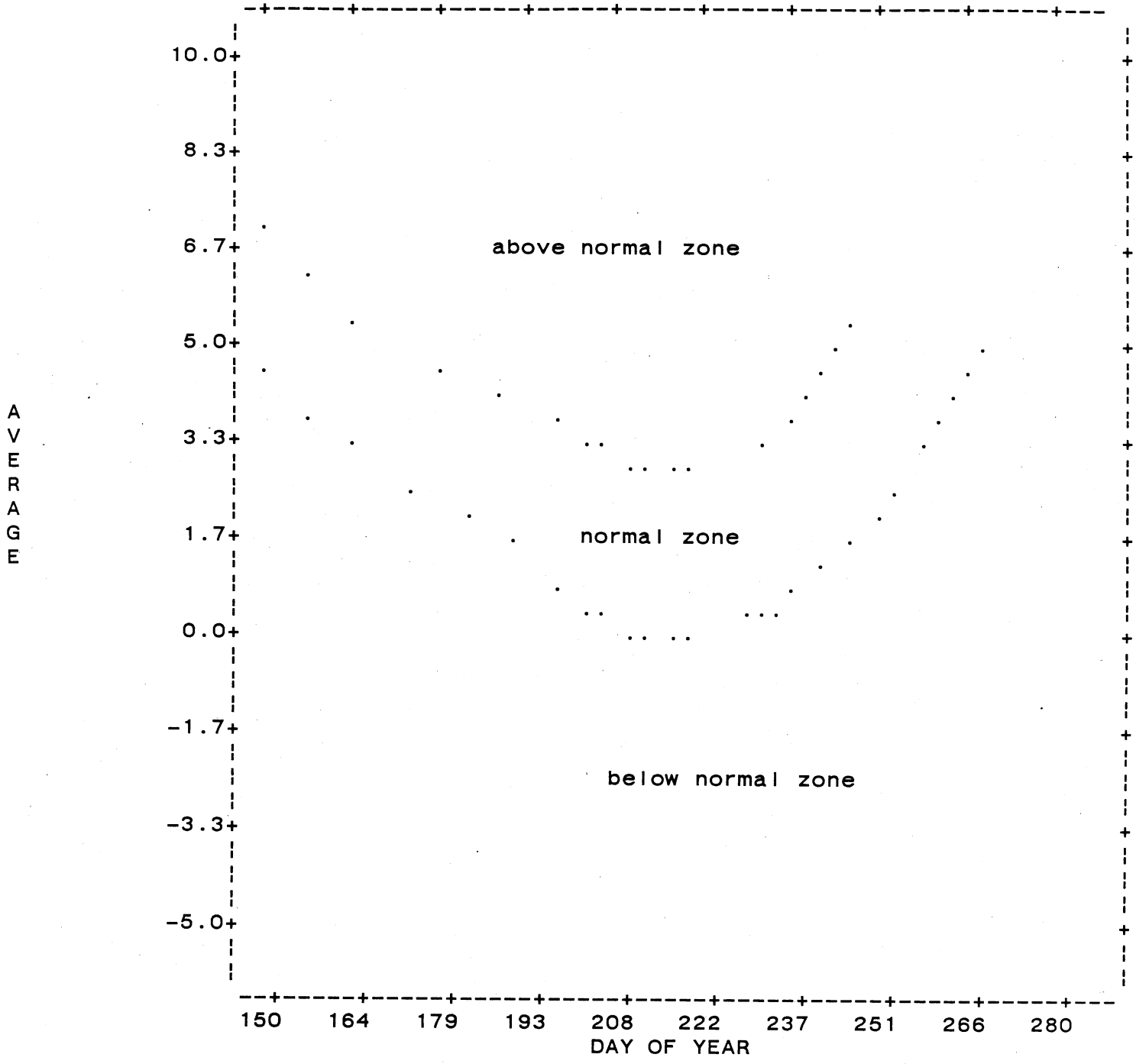
THE OPTIMUM CWSI

MUST BE ESTABLISHED

FOR EACH CROP

OPTIMUM VALUES DEPEND ON :

* CROP TYPE/PRODUCTIVITY RESPONSES
* IRRIGATION SYSTEM / SOIL TYPE
* MANAGEMENT OBJECTIVES


10.0
8.3
6.7
5.0
3.3
1.7
0.0
-1.7
-3.3
-5.0
AVERAGE
above normal zone
normal zone
below normal zone
150
164
179
193
208
222
237
251
266
280
DAY OF YEAR

CWSI FLUCTUATES

AROUND AN AVERAGE

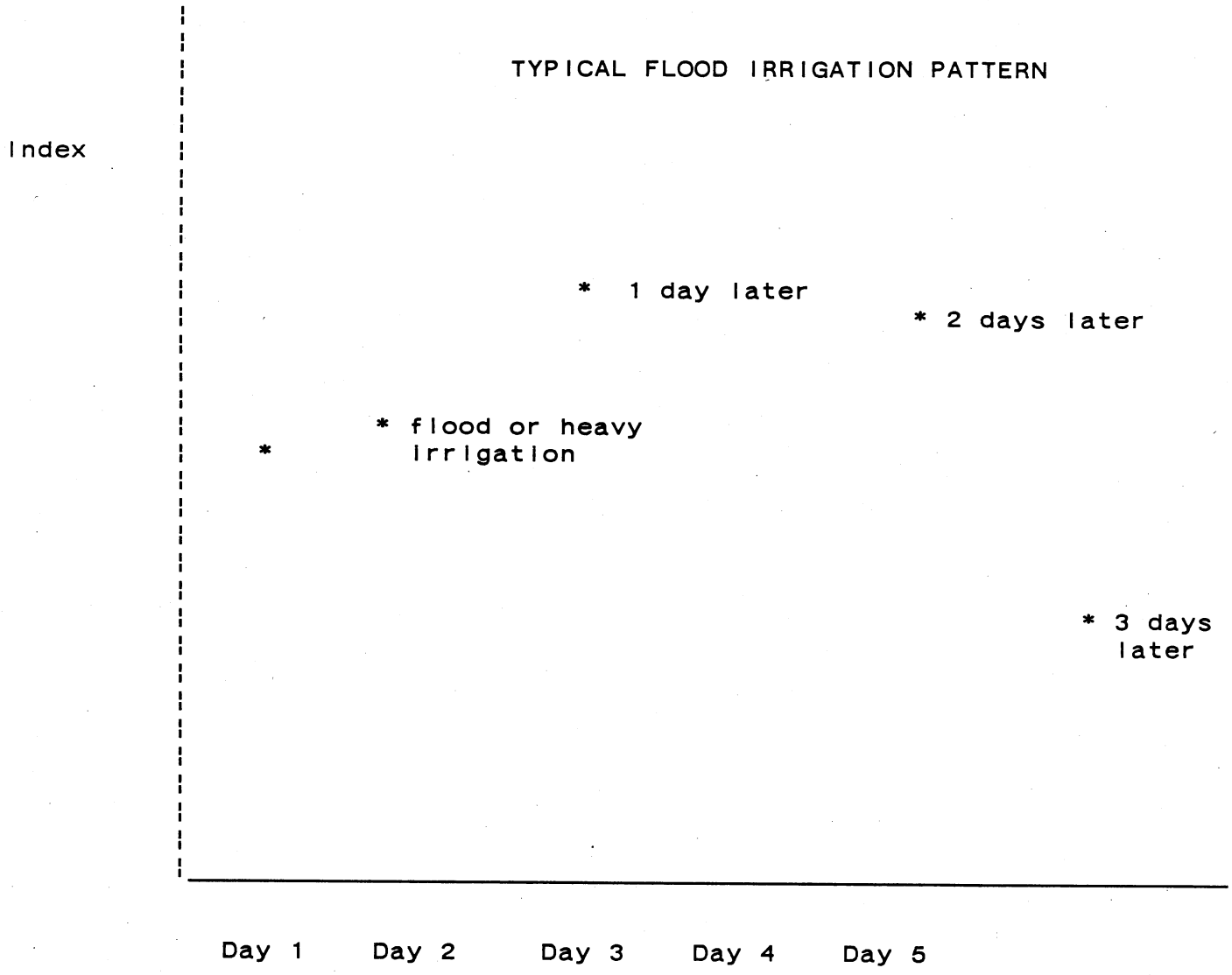
- THE SCHEDULER IS NOT A VOLTMETER

- SAMPLING IS THE KEY TO OBTAINING A GOOD AVERAGE

MAIN INFLUENCES

ON CWSI

- SOIL TEMPERATURE (when ground cover is incomplete)
- TIME OF DAY
- CLOUDS
- IRRIGATION


TYPICAL FLOOD IRRIGATION PATTERN
Index
* 1 day later
* 2 days later
* flood or heavy irrigation
*
* 3 days later
Day 1
Day 2
Day 3
Day 4
Day 5

OTHER EFFECTS ON CWSI

- WIND
- VARIETIES
- AGE OF PLANT
- FERTILIZER
- COMPACTION
- TILLAGE
- CHEMICAL APPLICATIONS

TECHNICAL TRAINING SEMINAR

I. PLANNING OBSERVATIONS

SAMPLE:

* RECENTLY IRRIGATED AREAS
* AREAS WHERE SOIL MOISTURE IS MONITORED
* AREAS WHERE PROBLEMS MAY OCCUR

PLAN :

* HOW DATA WILL BE RECORDED AND ANALYZED. COMPUTER SOFTWARE IS AVAILABLE TO ASSIST.

PREPARATION:

* KEEP IT CLEAN, ESPECIALLY THE LENS
* ALLOW HARDWARE TEMPERATURE TO ADJUST TO AMBIENT CONDITIONS

TECHNICAL TRAINING SEMINAR

USING THE SCHEDULER IN THE FIELD

I. PLANNING OBSERVATIONS

II. PROPER ENVIRONMENTAL CONDITIONS

III. SAMPLING TECHNIQUES

IV. CROP SPECIFIC RECOMMENDATIONS

TECHNICAL TRAINING SEMINAR

III. SAMPLING TECHNIQUE

* SAMPLE IN THE FIELD, NOT FROM ROADWAYS (or trucks)

* KEEP THE SUN AT YOUR BACK

* KEEP THE GUN AT LEAST 3 FEET ABOVE THE TOP OF THE SOIL

* USE A CONSISTENT AIMING TECHNIQUE

* AIM AT A SPOT NO MORE THAN ABOUT 30 FEET FROM WHERE YOU ARE STANDING, UNLESS YOU ARE USING A LADDER. 30 FEET AWAY REPRESENTS AN AREA OF ABOUT 150 SQUARE FEET.

* AIM AT LEAST 2 SECONDS BEFORE SQUEEZING THE TRIGGER

* TAKE SAMPLES IN MORE THAN 1 LOCATION

* AT THE FIRST SAMPLE LOCATION, TAKE REPEATED READINGS UNTIL THE AVERAGES OF CONSECUTIVE SAMPLES ARE WITHIN 0.5 UNITS OF EACH OTHER

II. PROPER ENVIRONMENTAL CONDITIONS

TIME OF DAY:

* ONE HOUR AFTER SOLAR NOON IS BEST, BUT AT LEAST BE CONSISTENT

* TAKE READINGS ONLY IN BRIGHT SUNSHINE

* WAIT FOR 1 MINUTE FOR CROP TO RE-WARM AFTER A CLOUD PASSES FROM IN FRONT OF THE SUN

* LOW WIND SPEED IS PREFERRED (less than 10 miles per hour). CWSI MAY DECREASE 1-2 UNITS UNDER HIGH WINSPEED.

IV. CROP SPECIFIC RECOMMENDATIONS

EACH CROP IS DIFFERENT. WE PROVIDE A SERIES OF KNOW-HOW BULLETINS TO ASSIST USERS IN APPLYING CWSI READINGS TO SPECIFIC CROPS.

TECHNICAL TRAINING SEMINAR

SUPPORT SOFTWARE

HARDWARE:

* IBM COMPATIBLE
* 180 K MEMORY REQUIRED

FUNCTIONS:

* IMPORT SCHEDULER DATA INTO THE P.C.
* PERMANENT DATA STORAGE
* DAILY GRAPHS AND PRINTED REPORTS
* HISTORICAL GRAPHS AND PRINTED REPORTS
* EXPORT DATA SELECTIVELY FOR USE BY OTHER PROGRAMS.